Draft

Appendix C

Europa Orbiter

Mission and Project Description

APPENDIX C

EUROPA ORBITER
MISSION AND PROJECT DESCRIPTION

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EUROPA ORBITER
MISSION AND PROJECT DESCRIPTION

1. Introduction

This appendix provides background information about the Europa Orbiter mission and pointers to the present body of relevant scientific knowledge. This information is to be used in conjunction with Appendices A and B by proposers in preparing a formal response to NASA AO 99-OSS-XX, Outer Planets Program Announcement of Opportunity.

This document contains general information, requirements, technical descriptions, and performance and interface envelopes that are pertinent to the preparation of proposals in response to the Europa Orbiter part of the AO. Also given is a detailed description of the activities for which the selected Principal Investigators (PI's) and Team Members will be responsible. Information from the AO is repeated only if necessary for continuity of content. In the event of conflict between the provisions of the AO and any appendix, the AO takes precedence.

It is important to note that the reference mission described here is only one of several options under study. This AO will result in the selection of three Europa Orbiter Science Investigations, the leaders and members of which will become members of the Europa Orbiter Integrated Implementation Team.

The science investigations proposed by the winning teams, as well as the reference mission described in this appendix, will evolve together into an end-to-end mission that best meets the science objectives within the strict cost cap. The actual Europa Orbiter mission that is implemented may differ substantially from the reference mission and the details of the winning science investigation proposals.

NASA has not committed to this project, nor this reference mission, nor to any specific launch schedule, launch vehicle, power source, Project budget, or funding profile.

The word "mission" means the Europa Orbiter mission. "Spacecraft" includes all launched engineering hardware and software. The term "flight system" includes all launched hardware and software for both engineering and science functions. The term "Europa Orbiter" may be used to refer either to the spacecraft itself or to the Europa Orbiter mission (as in "…will be developed for Europa Orbiter"). The word "project" is used in this document to refer to the

Outer Planets/Solar Probe Project; Europa Orbiter is one of the three missions assigned to this Project.

2. Overview

2.1 Science Objectives

2.1.1 Mission Overview

The Europa Orbiter mission will deliver a spacecraft into low orbit about Jupiter's moon Europa to allow investigation into the question of whether or not a liquid water ocean exists under its frozen surface and to characterize Europa for possible future exploration. This mission will allow fundamental questions to be addressed concerning the history of this unique satellite and the possibility that Europa has now or in the past harbored a habitat hospitable to life. The Galileo mission has provided substantial evidence that such an ocean did at least at one time exist.

The reference mission calls for the launch of a single spacecraft on a direct trajectory to Jupiter in November 2003. The spacecraft is captured into orbit about Jupiter where a series of a dozen or more gravity assists from close satellite flybys are used to extract energy from the trajectory in preparation for insertion into orbit about Europa. The orbit about Europa will be at high inclination to facilitate global coverage by the ground track and at low altitude (~200 km) to provide high spatial resolution sampling. The nominal duration in Europa orbit is 30 days, which provides for about 300 orbits around the satellite. The intense radiation field in Jupiter's magnetosphere at the distance of Europa's orbit limits the lifetime of this mission and presents an engineering challenge to design survivable systems within the severe mass constraints of the mission.

A strawman science payload has been used to create a conceptual design of the mission and spacecraft. This strawman payload includes an imaging system, a laser altimeter, and a radar sounder, along with the usual radio science measurement capability provided by the spacecraft telecommunications subsystem. A different payload could be selected based on proposals received in response to this AO. The measurements planned to be made could include radar sounding of the thickness of Europa's surface ice layer, radiometric tracking for gravity field determination, multispectral imaging of global and local surface features, and laser altimeter measurements of the precise shape of the body including the bulge produced by Jupiter tides. These measurements should permit a clearer picture to emerge of the interior structure and geologic history of Europa.

Europa Orbiter operations at Jupiter will consist of three phases: (1) Satellite Tour: The "Galileo-like" ballistic phase following Jupiter Orbit Insertion (JOI), expected to last approximately 1-2 years; (2) End Game: Final Europa encounters and associated maneuvers necessary to achieve Europa orbit, expected to last approximately 5 months; and (3) Europa Orbit: A precessing high-inclination circular orbit of Europa at altitudes between 100 km and 200 km, with a nominal mission lifetime of 1 month.

2.1.2 Science Objectives

The Europa Science Definition Team carefully considered the range of science objectives appropriate to a first detailed orbital mission to Europa. These were then prioritized, and their final ranking, endorsed by the Solar System Exploration Subcommittee, appears below. Group 1 objectives are considered absolutely essential to the first orbital mission; Group 2 objectives are considered important but not mandatory. The groupings resulted in a scientifically compelling set of focused goals for a Europa Orbiter mission:

Group 1 Objectives:

- Determine the presence or absence of a subsurface ocean;
- Characterize the three-dimensional distribution of any subsurface liquid water and its overlying ice layers; and
- Understand the formation of surface features, including sites of recent or current activity, and identify candidate landing sites for future lander missions.

Group 2 Objectives:

- Characterize the surface composition, especially compounds of interest to prebiotic chemistry;
- Map the distribution of important constituents on the surface; and
- Characterize the radiation environment in order to reduce the uncertainty for future missions, especially landers.

2.1.3 Measurement Requirements

Selected investigations must directly address the Group 1 objectives of the mission during the Europa Orbit phase of the mission. The Europa Science Definition Team provided the following recommended requirements for a set of measurements to be made in order to achieve the Group 1 objectives using its strawman payload.

2.1.3.1   Gravity

Europa is distorted by the tide-raising potential of the Jovian gravitational field. Europa's changing shape introduces a periodic term into Europa's gravitational potential. This term is proportional to k_2, the gravitational Love number. The tides cause changes of ~1% in the second-degree harmonic gravity coefficients J_2, C_{22}, and S_{22}. Doppler radio tracking of the spacecraft will allow these gravitational terms to be determined, thereby determining k_2 as well. A completely solid ice layer has k_2 ~0.02, while a liquid ocean overlain by 25 km of ice has k_2 ~0.28. The measurement objective of the gravity investigation is to determine Europa's k_2 Love number to an accuracy of ±0.001. An accuracy of ±0.03 would be sufficient to infer the presence of a subsurface ocean.

In order to measure the second-degree harmonic gravity coefficients to sufficient accuracy, radiometric tracking data are required from an orbit altitude between 100 and 300 km with an inclination >70° and eccentricity <0.1. Two different orbital altitudes are needed during the mission preferably with their orbital planes separated by >10° of precession. Subsurface trajectory disturbances must be minimized. Two-way X-band Doppler tracking to an accuracy of 0.1 mm/sec (1   with one-minute compression) over a total of three Europa days should be sufficient. One day of tracking should be from the higher or slightly eccentric orbit (~300 km apoapsis), and the other two days of tracking from an altitude of 200 km or less. Tracking arcs should be as long as possible without any spacecraft-induced trajectory disturbances.

2.1.3.2   Altimetry

The height of the tidal bulge on Europa is proportional to the h_2 Love number, which in turn depends on the density and elasticity of Europa. The tidal bulge height varies as Europa travels in synchronous rotation along its orbit because of its slight orbital eccentricity (e~0.01). At perijove, the bulge's height reaches a maximum, H_{max}, equal to 24 h_2. For a solid ice shell, h_2~0.04 and H_{max}~1 m; for a global ocean lying beneath an ice shell tens of kilometers thick, h_2~1.2 to 1.3 and H_{max}~30 m. By measuring the height of the tidal bulge throughout Europa's orbit, the magnitude and phase of h_2 can be determined. A measurement of h_2 to ±0.02 is required.

In order to measure the tidal bulge with sufficient accuracy, a high-inclination, near-circular orbit at an altitude of <200 km is required to provide repeated high-resolution, near-nadir altitude measurements over the regions of maximum tidal deformation. The orbital radius must be reconstructed to <1-m accuracy. This level of orbit determination requires simultaneous X-band Doppler tracking over a substantial fraction of each orbit, along with ranging data to an accuracy of ~1 m (1   ).

2.1.3.3 Radar Sounding

The objective of a radar sounding experiment is to detect a possible ice/liquid interface. The probability of making such a detection is maximized by sounding along ground tracks globally distributed in latitude and longitude. The spatial resolution should be at the scale of the major surface features, i.e., ~10 km. The depth resolution needs to be ~100 m near the surface and 10% of the depth at depth.

The thickness of ice that can be sounded on Europa is determined by the absorption of electromagnetic waves in the ice (which is dictated by the temperature and impurity content) and scattering characteristics of the ice body (including the surface and basal interfaces as well as any volume scatterers). The scattering properties of any assumed sounding model for Europa as well as the Jovian radio noise environment are frequency dependent, so the limits on the maximum (and minimum) characterizable depths to a Europan ocean are critically dependent on instrumentation and processing parameters.

The electrical conductivity of ice and hence its absorption of radar waves is dependent on the ice temperature and the nature and concentration of impurities it contains. The strong temperature dependence of the electrical conductivity of ice means that the temperature profile in the Europan ice layer is a major factor in total radar absorption loss. Chyba et al., (1998) pay particular attention to the temperature profile, which is probably governed both by the well known surface and assumed basal melting temperature and by the uncertain distribution of tidal heating through the ice shell. Taking this into account, a reasonable temperature profile $T(z)$ as a function of depth from the surface is:

$$T(z) = T_s \exp(z / h)$$

where the surface temperature is T_s at $z=0$ and $h=b/\ln(T_b/T_s)$, where b is the ice thickness and T_b is the temperature at the ice base. The surface temperatures on Europa range from about 100 K at the equator to 50 K at the poles, T_b is determined by the pressure melting point of ice, but for Europa this is a minor effect, and the basal temperature will be close to 270 K for reasonable ice thickness. The profiles for surface temperatures of 50 K and 100 K are shown in Figure 1.

A range of possible radar absorption's could be present in Europan ice depending on its impurity content. Table 1 shows the relevant radar parameters for the various ices discussed here. Since the radar absorption is governed by a dependence on temperature, which is exponential to a good approximation with depth, the two-way absorption's per km can be found for a given surface temperature independent of ice thickness. In Table 1 we take values of 50 and 100 K as representative of poles and equator.
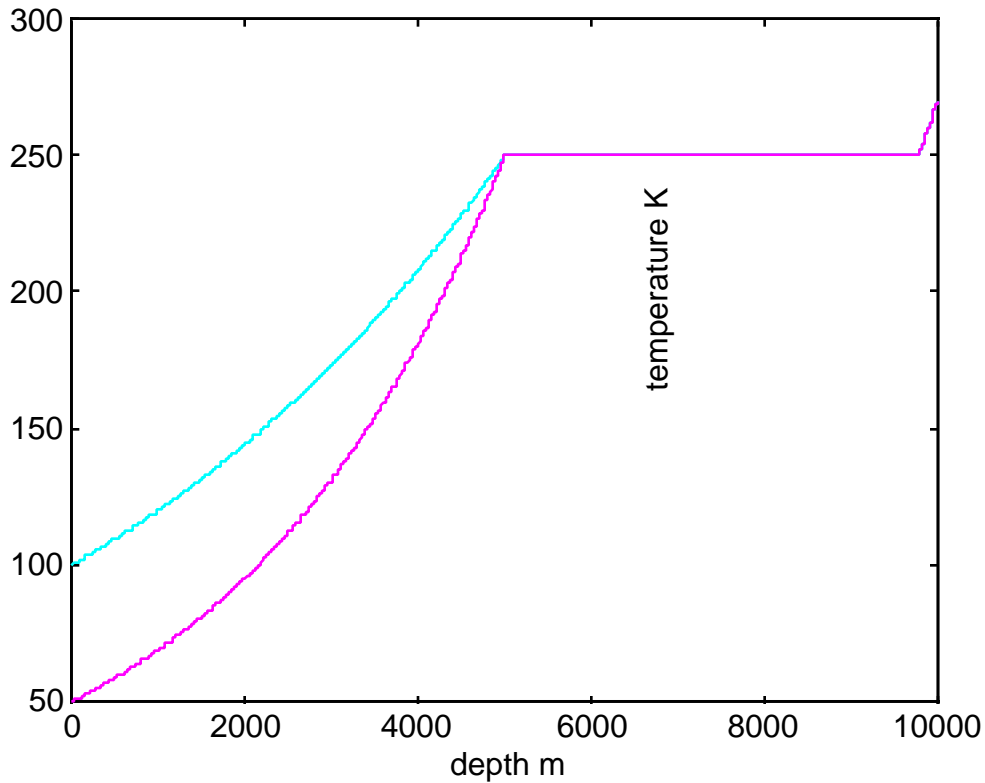
Figure 1.   Temperature distribution through a 10 km ice crust, with surface temperatures of 100 K and 50 K. Also shown is the temperature profile for a 5-km thick conducting lid overlaying an isothermal convecting layer at 250 K with a lower conducting boundary.

To characterize the expected radar returns from Europa's surface, the relevant surface inputs to scattering models must be specified. The best available data for Europa's large-scale surface characteristics are obtained by using stereo-derived DEM (digital elevation models) obtained by using Galileo imagery. An examination of the slope probability density function (pdf) shows that the distribution of slopes is generically characterized by unimodal distributions with large tails, which are not well fit by Gaussian distributions. The tails of the distributions exhibit slopes that can be greater than the angle of repose.

As a conservative assumption, the two-scale scattering model [Tsang, 1985], which has been used successfully to characterize radar returns from a variety of rough surfaces on Earth, can be assumed to apply. The specular, or geometric optics, return can be shown to be proportional to the product of the Fresnel reflection coefficient times the pdf of surface

Table 1. Comparison of various ice types and radar absorption's

Ice Type	Impurity Content	(dB/m) at 251 K	2 way attenuation (dB/km) T_s(50 - 100 K)	2 way attenuation (dB/km) to convecting layer at 260 K T_s(50 - 100 K)	2 way attenuation (dB/km) to convecting layer at 250 K T_s(50 - 100 K)	Notes
Pure Ice	Nil	0.0045	1.4 - 2.4	0.5 – 0.9	0.2 – 0.3	Glen and Paren (1975)
rock/ice	1% lunar soil	0.008	5 – 6	4 – 4.7	3.6 – 4.1	Chyba et al., (1998)
rock/ice	10% lunar soil	0.01	8 – 9	7 - 8	6 – 7	Chyba et al., (1998)
Chlorine dominated Europa ice/ocean	3.5 ppt chlorinity ocean	0.05	14 – 24	10 - 17	7 - 12	Marine ice scaled from Earth ocean, $k_o = 3 \times 10^{-3}$
Sulfate dominated Europa ice/ocean	10 ppt chlorinity ocean	0.15	36 - 61	25 - 44	18 - 31	Kargel, 1991; marine ice, $k_o = 3 \times 10^{-3}$
Ronne Ice Shelf marine ice	400 μM Cl (0.025 ppt salinity) ice	0.15	36 - 61	25 - 44	18 - 31	Moore et al., 1994 LF data core samples
Baltic Sea Ice	ice grown in 3 ppt sea water	0.85 (at 270 K)	50 - 85	26 - 43	16 - 27	200 MHz radar measurement

slopes. Using, as a conservative estimate, the slope pdf for the Pwyll region, the predicted geometrical optics contribution decreases linearly in dB space from about 10 dB to -20 dB as the incidence angle varies from 0 deg to about 20 deg. A conservative estimate of the geometric optics contribution is to assume that very few surface glints are obtained for surface slopes greater than the angle of repose. This produces a geometric cross section that decreases rapidly for incidence angles greater than 30 deg. Since the geometric cross section merely reflects surface glints, it is nearly frequency independent. As a conservative estimate, it can be assumed that the small-scale surface exhibits the same spectral decay as the measured large-scale surface, and that the small-scale surface RMS surface height varies between 1 to 10 m.

Summarizing these results, it can be expected that for incidence angles smaller than 30 deg, the expected total cross section is dominated by the geometric optics return, which is frequency independent. This result is attributable to the rugged nature of Europa's terrain and the large slopes that can be encountered for some of its unusual features. For incidence angles greater than 30 deg, the uncertainty in the expected cross section increases due to difficulties in assessing the presence of slopes greater than the angle of repose. For incidence angles greater than 30 deg, the cross section can vary between -40 dB to -20 dB depending on the surface characteristics present.

The dominant component from the bottom return is due to return from the first Fresnel zone at any ice-water interface. The attenuation of the coherent return will be greater at higher frequencies for the case of significant height variations at this interface.

Earth-based radar sounding of Europa at 3.5- and 13-cm wavelengths suggests that Europa's ice crust contains many higher-order multiple scattering inhomogeneities in its uppermost few meters at decimeter scales, which prohibits probing of the ice to any great depth at these radar wavelengths. However, sounding at 70-cm indicates that such scattering inhomogeneities are far fewer at that wavelength. Therefore, radar sounding is best done at wavelengths greater than a few meters for adequate surface penetration. Given the unknowns in Europa's subsurface structure and temperature profile, it would seem desirable to be able to make radar sounding measurements at multiple wavelengths, with a variety of beam sizes, with adjustable integration times in both coherent and incoherent modes. A signal cancellation channel to remove any off-nadir returns is also desirable.

2.1.3.4 Imaging

The primary goals of the imaging observations are to identify regions of the most recent or continuing geological activity, to map Europa's surface in sufficient detail to characterize the processes underlying its morphology and history, and to significantly improve upon Galileo's surface resolution coverage with sampling of all types of features at high resolution.

To meet these goals, global mapping in at least two colors (violet and near-IR) is required at <300 m/pixel resolution. In addition, sampling of ~1% of the surface at 3 - 30 m/pixel resolution in a single color is needed. A high-inclination orbit is necessary to allow imaging with a global reach. Wavelength capability out to at least 1 μm is required to discriminate known color/stratigraphic relationships.

2.1.3.5 Pre-Europa Orbit Measurements

Once in Jupiter orbit, numerous opportunities may arise for useful scientific observations of Europa and possibly other parts of the Jovian system, both for instrument checkout and calibration and for additional scientific return. The Project plans to begin limited science operations following JOI, the scope of which will be determined when more detailed mission plans are developed following selection of investigations. Pre-Europa Orbit phase science planning will be constrained by a number of factors and will be considered under the following guidelines:

- The mission design will be driven by the requirement to minimize the delta-V, absorbed radiation dose, and duration of the Tour/Endgame in support of the Europa Orbit mission objectives, not by Tour or End Game science opportunities.
- Spacecraft and ground system requirements and resources will give priority to Europa Orbit phase requirements.
- Essential instrument checkout and calibration will be given priority over other science activities.
- Science observations which directly address or enhance the primary Europa Orbiter mission objectives will be given priority over other Jupiter system observations.
- Investigations will be selected on the basis of meeting the primary objectives of the mission while in Europa orbit. Proposals should also address the minimum required pre-Europa Orbit science checkout and calibration requirements, and present only briefly the investigations' general capability to support pre-Europa science activity.

2.1.4 Strawman Payload

The following strawman list is an illustrative science payload that, properly realized, would likely satisfy the primary objectives of the Europa Orbiter mission. Of course, none of the instruments in this illustrative set has been selected (with the single exception of the spacecraft transponder), and alternative and better approaches to meeting the Group 1 objectives may well exist. Novel concepts that can meet the Group 1 objectives are encouraged.

2.1.4.1 Radio Science

The spacecraft transponder, which will serve as the basis of the Doppler tracking gravity measurement experiment, is a facility instrument provided by the project. The combined spacecraft telecommunications subsystem and DSN ground stations links can provide two-way X-band Doppler tracking to an accuracy of 0.1 mm/sec (1) with 30 seconds of integration time per data point.

2.1.4.2 Laser Altimeter

The strawman laser altimeter is based on Clementine heritage. It has an estimated mass of 5.1 kg (including 2 kg of radiation shielding) and has an average power level of 7.5 w (15 w peak). Its transmitter is a diode-pumped, solid-sate, Cr:Nd:YAG, Q-switched, variable-mode laser operating at 1064 nm wavelength. Pulse lengths are 5 ns and contain 30 mJ. The transmitter volume, including a high-voltage power converter, is 20x8x8 cm. The transmitted beam has 0.5-mrad divergence providing a 100-m footprint from 200 km altitude.

The receiver optics has a 5-cm aperture and is boresighted to the laser to within 1 mrad. Volume is estimated at 15x10x10 cm for the receiver. It appears that the altimeter receiver optics and the narrow-angle imaging optics could possibly be shared to save mass, but the strawman design does not assume such sharing. The detector could be either a silicon-avalanche photodiode or a photomultiplier tube. A cover and purge are included for contamination protection in the Shuttle.

A 1/s pulse rate provides measurements spaced about 1.34 km apart along the ground track for a 200-km altitude orbit. Each measurement generates about 2000 bits of data; the 1/s pulse rate yields a raw data rate of 2 kbps. Assuming 5:1 data compression prior to data storage results in a data rate to memory of 400 bps. Continuous altimetry simultaneous with radio tracking over half of two orbits would generate a data volume of 3.3 Mb for subsequent downlinking.

2.1.4.3 Radar Sounder

An ice penetrating radar (IPR) system is being developed as a consortium instrument. Investigators may propose in response to the AO to conduct investigations with the IPR in the same way that they would propose to conduct investigations with a facility instrument. Because the IPR is being developed as a consortium instrument provided by the Project, independent IPR instrument designs are not solicited by this AO; nor should an IPR be included in an integrated payload proposal.

The Europa sounder radar concept hardware consists of a Yagi antenna, 100-W transmitter, and a sensitive receiver with digital output to the spacecraft computer bus (see Figure 13). Data reduction is achieved in the radar hardware by employing a sensitivity time control (STC) to reduce the echo dynamic range and a "deramp" mixer to reduce the signal bandwidth necessary for processing. Further data reduction is performed in the processor by azimuth compression and echo averaging. 50 MHz (6-meter wavelength) was chosen as the primary operating frequency for the radar system. Figure 2 shows a block diagram of the radar.
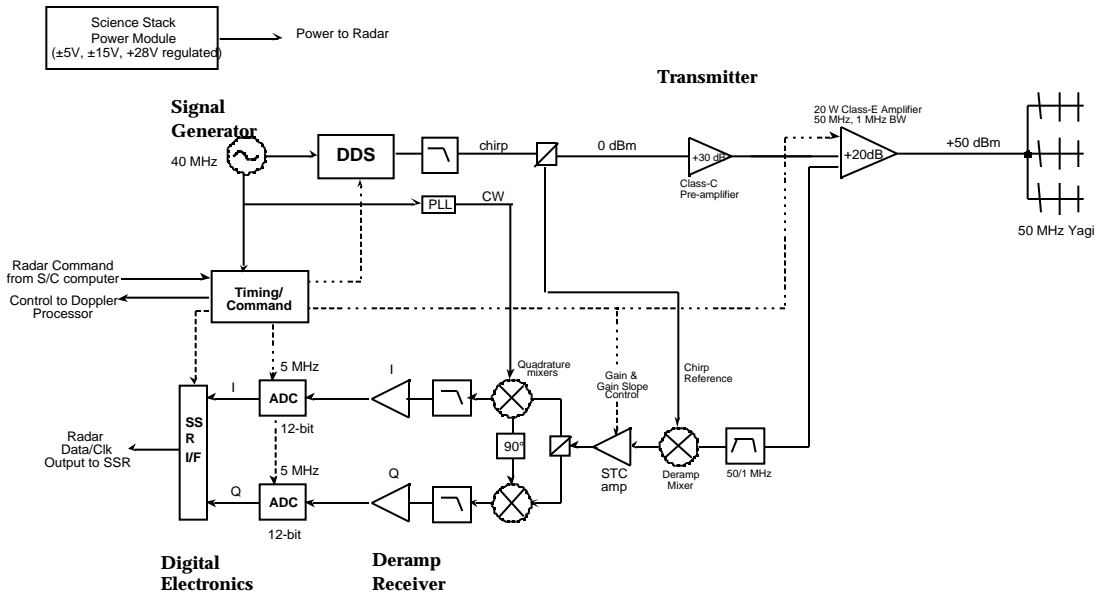
Figure 2.   Europa Radar Sounder block diagram

An array of three standard 3-element Yagi antennas is proposed for this system. This antenna array will form a relatively narrow beam pattern. The array will be pointed toward Europa with its baseline-oriented perpendicular to the track of the spacecraft.

Figure 3 shows the numerical simulations of the antenna pattern for 50 MHz in both the E and H planes, the planes in the cross- and along-track directions of the spacecraft, respectively. As shown in the figure, the antenna array has a maximum gain of about 12 dB at nadir, and has a 3-dB beamwidth of about 20° and 100° in the cross- and along-track directions. The first sidelobes in the cross-track direction are about 37° away from the nadir direction and are about 13 dB down in the gain level. Since the antenna array will be used for both transmitting and receiving, the total effective gain will be 26 dB down compared to the
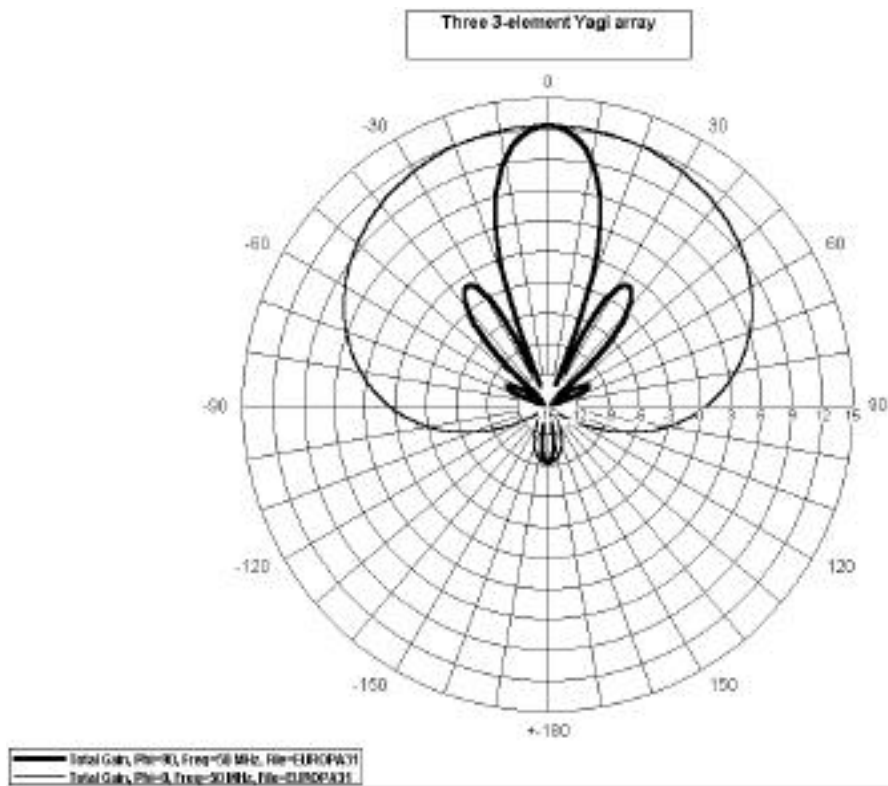
Figure 3. Simulated antenna patterns in the cross- and along-track directions. The 3-dB beamwidth is about 20º in the cross-track direction, and about 100º in the along-track direction.

main lobe. The other attractive characteristic of Yagi antennas is the high front-to-back ratio. With the current design, the front-to-back ratio at 50 MHz is about 20 dB.

The radar transmits a linear-FM (chirp) waveform using direct digital synthesis (DDS) technology. The DDS is also used to derive the required local oscillator (LO) frequencies necessary for up and down conversion. A very efficient and high-power transmitter amplifier will enable the use of short duration pulses in the system design. The high dynamic range requirement results in the need for dynamic gain control. The deramp design uses the transmit chirp waveform to downconvert the chirp rather than using a conventional LO signal. This deramp technique will reduce the system data rate by performing analog chirp compression. A STC (variable gain amplifier) is used to reduce the dynamic range requirement by weighting the deramped chirp as a function of time.

The digital system consists of the analog-to-digital converters (ADC), which sample the data with 12-bit resolution at 5 Msps, and command registers. To keep the digital system simple, the radar data are sent directly to the onboard solid state recorder provided by the spacecraft, which can then be accessed by the spacecraft-provided onboard data processor.

The total sounder instrument has a mass of 7.7 kg and uses an average of 14.2 W of power.

An additional 10-MHz center frequency, two-channel radar system could be incorporated for 1.1 kg additional mass and 0.8 W additional power. The 10-MHz radar would operate instead of the 50 MHz and have a two-antenna (dipole and monopole) system sharing the same structure as the Yagi. Not all the issues of the antennas have been worked out, especially how the 2-m monopole antenna would share the center Yagi element. Radar team proposers should include a brief description of the potential benefits to their investigation of adding the second frequency channel.

Table 2 gives the system parameters for the anticipated Europa radar sounder.

Table 2.   Europa Sounder system parameters.

Parameter	10 MHz (optional)	50 MHz
Transmit Power	100 W	20 W
Antenna Gain	2.1 dB	10 dB
Pulsewidth	500 µsec	500 µsec
Pulse Repetition Frequency	125 Hz	375 Hz
Bandwidth	0.85 MHz	0.85 MHz
Receive Channels	2-channel	1-channel
Receiver Dynamic Range w/ STC	90 dB	90 dB
A/D quantization	12-bits/sample	12-bits/sample

The expected return power levels, and hence ocean detectability, can vary substantially depending on the assumptions made about the attenuation due to the ice. As an example of expected detectability depths, Figure 4 presents the expected return power for the 50-Mhz design as a function of depth, assuming that the attenuation constant does not vary with depth for values of 2, 10, and 40 dB/km, which provides an envelope of the attenuation levels presented in Table 1. It has been conservatively assumed that the bottom interface backscatter cross section is 0 dB. The figure also presents the expected surface clutter contribution, assuming the surface scattering characteristics discussed in Section 2.1.3.c, and the use of Doppler processing, as discussed below. For reference, this figure also presents

the constant noise level expected on the anti-Jovian side. The noise level expected on the Jovian side is closer to -125 dBW.
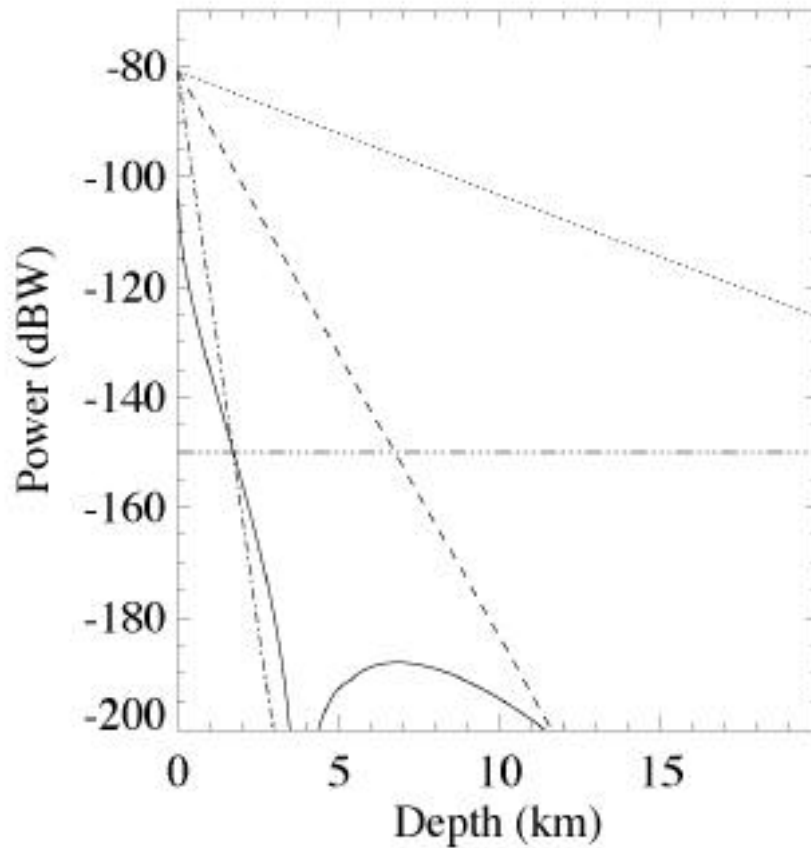
Figure 4.   Expected power levels for subsurface return for attenuation rates of 2 dB/km (dotted line), 10 dB/km (dashed line), 40 dB/km (dotted-dashed line). The return power from the surface is shown as the solid line, while the thermal noise level is the horizontal line. Assuming Doppler processing

Representative science data output capabilities of the Europa Radar Sounder are as follows. The baseline mode is expected to return to Earth all data collected by the sounder, processed on board into waveforms having depth and along-track resolutions equal to the radar's capabilities. A second mode offers waveforms averaged in depth resolution or in along-track spatial resolution, either version having a lower data rate than the baseline mode. The purpose of this mode is to allow survey radar sounding to co-exist with other Europa observations such as geodesy, or to adapt to any other data rate or data volume constraint. Finally, a third mode supports the digitized radar sounder complex data, prior to onboard waveform

processing, captured on a per-pulse basis. This mode, whose data rate and volume would far exceed routine operating capabilities of the sounder telemetry, requires onboard buffer storage prior to down-link at a slower rate. Data in this mode may be useful for initial validation of the sounder's performance and for specialized (and relatively rare) observations of selected regions of Europa.

"Waveform" in this discussion is meant to imply a mapping of signal strength as a function of delay time, which in turn is proportional to depth of penetration of the radar's emitted energy into the ice. Once the waveforms are returned to Earth, sequences of them may be combined to form profiles of ice penetration along the subsatellite tracks. Each waveform is the product of processing the observed echoes of several thousand individual pulses transmitted by the radar. The radar sounder and its onboard processing are designed (1) to resolve the along-track footprint size of each waveform to be as small as possible (typically < 2 km), (2) to resolve the depth measurements of scattering layers and potential ice/water interfaces (typically ~ 100 m), (3) to measure the mean altimetric elevation and large-scale roughness of the surface of the ice (estimated accuracy's for which are ~15 m and ~30 m, respectively), and (4) to estimate the radiometric properties of reflection and losses within the ice. Spatial (along-track) resolution is taken in this context to mean the size of each individual waveform's footprint after onboard (Doppler) processing, and depth resolution implies the size of each depth data bin.

The science waveforms to be produced by the Europa Sounder may differ from those described in these paragraphs. Implementation details of processing and waveform generation will be determined by the final design of the sounder. The actual waveform telemetry formats will take into account preferences and/or requirements of the science community, subject to constraints that may be imposed by the radar design, onboard processing resources, and the capacity of the data down-link.

The radar sounder, even at the relatively low pulse repetition frequency (PRF) of about 400 Hz suitable for the 50 MHz band when operating from 100 km above the surface, will be turning out approximately 100 times more data than the mission telemetry can accommodate continuously in real time. Onboard processing is essential to reduce the data burden to a manageable size.

The notional onboard processor strategy, outlined below, is a blend of conventional coherent and incoherent integration (known as "stacking" in the sounding community) augmented by similar integration's implemented in parallel data paths. Conventional coherent integration selects only those sounding data whose Doppler frequencies are at or near zero. The extra data paths arise at offset Doppler frequencies. The improvement in sounder performance is directly proportional to the number of such parallel Doppler paths incorporated into the

processors. The end result of the waveform processing is a single sounding waveform at each resolved along-track position.

The transformation of the pulse-to-pulse radar echo data into waveforms suitable for downlink telemetry to Earth is outlined in Figure 5. Following dynamic range compression and analog-to-digital conversion, the average rate of the raw data from the radar sounder is approximately 1 Mbps. These data are captured in the working memory of the coherent Doppler integrator. Subsequent steps operate on blocks of 64 input range lines at a time to generate coherent migration-corrected sounding waveforms in N parallel Doppler bins, (where $1<N<\sim25$, subject to processing limitations). These coherent waveforms are detected, registered along-track, and summed, all in the incoherent waveform integrator. The resulting waveforms represent the full-resolution sounding measurement capability of the radar. The telemetry format processor serves as the interface between the full-resolution waveforms and the data downlink system, matching the data delivered to the telemetry system to its mode requirements.

N parallel   *Accumulated*
coherent   *waveform vs.*   *Waveforms*
I&Q raw data   *waveforms*   *position (~6.5*   *according to*
(~1 Mbps)   *(~4 Mbps)*   *kbps)*   *Mode*

Echoes
from radar   →   Coherent (Doppler) integrator → Incoherent waveform integrator → Telemetry format processor → *To telemetry system*
sounder
digitizer
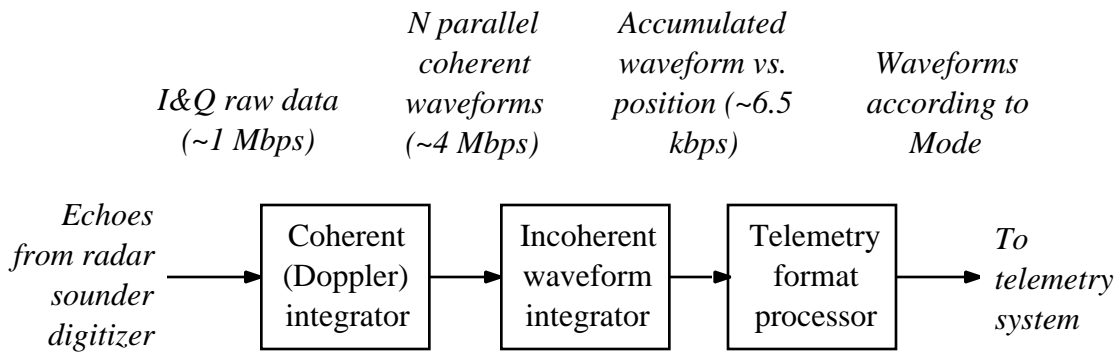
Figure 5. Concept of data flow from the radar sounder to the telemetry system

The nominal baseline radar sounding mode, denoted here as Mode 1, fits within the mission budget for data volume and data rate. The average Mode 1 data rate of 6.5 Kbps is sufficient for continuous telemetry of the full resolution waveforms and also is low enough that the data volume required by a full set of surface soundings is substantially less than 10% of the mission budget. On the other hand, if there were deeper data rate or volume constraints, then the sounder output data rate would have to be reduced, nominally to 1 Kbps, average. This low rate is designated Mode 2, which may be realized either by averaging waveforms in depth (Mode 2.1) or by averaging waveforms along-track (Mode 2.2).

Alternatively, higher rate data may be collected and stored in a buffer, then subsequently downlinked at a lower rate to the Earth. The internal (complex) data rate from the radar

sounder (prior to the waveform processors) is about 1 Mbps average. A reasonable lower limit on the useful amount of such data is about 15 seconds, which would be sufficient to allow the mid-beam portion of the antenna illumination to completely scan a given subsatellite point. This corresponds to about 15 Mb of data. Several such high-rate snapshots could be gathered as a matter of routine operation without overburdening the onboard data storage or downlink resources.

Mode 1 and Modes 2 are designed to transmit waveforms at or near the maximum applicable rate given the constraints imposed by current mission operations. In all modes, the approach is to downlink individual waveforms, each one to include a control word. The (real) waveforms will be represented by floating point magnitudes, one digital number per depth bin. The control word will provide: (1) the surface height (which is proportional to the delay time to the first reflection received at the radar), (2) the amplitude scaling factor, (3) the rate of change of the amplitude scaling factor with depth, (4) the radar PRF (which is a function of satellite height, and on which radiometric and geometric scaling depend), (5) spacecraft time (or an equivalent index of the waveform's along-track location), (6) mode flag, and (7) ancillary data. Note that the amplitude scaling factor and its slope are required in response to the very large dynamic range of reflected power expected for the sounding echoes.

In all modes, data will be included that captures received signal strength both before the first surface reflections and deeper than the nominal 20 km. The early returns are valuable because: (1) they provide a sample of the prevailing noise, including additive system and ambient environmental noise; (2) they allow an estimate of the presence of sensible range ambiguities; (3) they support estimation of the mean (large-scale) surface roughness, and (4) they serve as a measure of the fine-scale distance between the radar and the surface, thus allowing the sounder to serve as a radar altimeter.

Mode 1: Full-Resolution Waveforms (FW).

A notional limit of 6.5 Kbps will allow 256 depth bins to be encoded at 20 bits floating point together with a control word of about 1.4 Kb. Thus, a sequence of waveforms in Mode 1 will support generation by an investigator of a profile consisting of soundings each having several hundred degrees of freedom, depth resolution of 100 m over the full 20 km ice thickness, and spare depth bins to cover early returns prior to the first surface and late returns to flag deeper responses. This is the default standard operating mode for the sounder.

The satellite's orbital height is the primary determinant of the along-track sounding interval, which will be about 1.4 km for a satellite height of 100 km expanding to about 1.9 km from a height of 200 km. The statistical degrees of freedom within each waveform, which are

proportional to the number of incoherent integration's available, is to first order a constant over this range of orbital heights. Average data rate decreases with increasing orbit height, since one waveform is produced for each resolved along-track sounding interval.

Europa completes one revolution within about 3.5 days. If the radar sounder were to gather data for 7 days at a 50% duty factor, it could generate a complete set of surface soundings, subject, of course, to the cross-track spacing of adjacent orbits. Such a Mode 1 data set would require less than 2 Gbit.

Mode 2: Averaged Waveforms (AW).

The data rate or volume available to the radar may preclude full resolution sounding for portions of the mission. The averaged waveform modes are designed to meet this contingency, fitting their science return within a 1-Kbps limit. Consider one example. If the radar sounder were to gather data in Mode 2 for 7 days at a 50% duty factor, it could provide a survey of the surface, subject to the reduced resolution implied by averaging. Such a survey in Mode 2 would require only about 300 Mbits total data volume.

Mode 2.1: Averaged Depth Waveforms (AW-D).

One means of reducing the available data rate for each individual waveform is to aggregate resolution cells that lie at deeper levels, consistent with the depth resolution requirement: the greater of 100 m or 10% of depth. One means of doing this is described in Table 3. In this mode, waveforms would be downlinked that correspond to full resolution along-track, but which have selective depth averaging applied. The amplitude would be encoded as 16-bit floating-point digital numbers at 55 depth stations, leaving about 120 bits available for the control word from an orbital height of 100 km, expanding to several hundred bits for the control word from 200 km height. With such a small control word, it may be necessary in this mode to link control words across a group of waveforms.

Table 3.   Mode 2.1 depth bin averaging plan

Depth interval (km)	Number	Resolution (m)
Pre-surface	5	170*
0 - 2	20	100
2 - 5	12	250
5 - 9	8	500
9 - 13	4	1000
13 - 19	4	1500
19 - 21	2	2000

*The in-ice design resolution of 100 meters expands to about 170 meters in free space.

Mode 2.2: Averaged Surface Waveforms (AW-S).

An alternative means of reducing the available data rate for each individual waveform is to retain full depth resolution, but to aggregate adjacent waveforms along-track, sufficient to meet the governing average data rate of 1 Kbps. One means of doing this is to sum several sequential full-resolution waveforms, and to downlink the result at reduced dynamic range. In this mode, from an orbital height of 100 km, the averaged surface waveforms would have along-track resolution of about 5.6 km, and they would retain 100 m resolution at all depths. The amplitude would be encoded as 16-bit floating-point digital numbers at 220 depth stations, leaving about 480 bits available for the control word. The corresponding mode from 200 km height would need to average only three waveforms along-track to accomplish virtually the same performance: 5.7 km along-track resolution, 100 m depth resolution, and 16-bit floating-point radiometric resolution, with about 500 bits available for the control word.

Mode 3: Radar Sounder Data Record (RDR).

The average data rate of the radar sounder after the analog-to-digital conversion is on the order of 1 Mbps. As introduced above, these data could be captured directly and placed in memory, there to await an opportunity to downlink the lot at a slower rate. This mode should be regarded as a special case, to be used only when fully justified. Mode 3 can operate in parallel with Mode 1 or with one of the Mode 2 options. Thus, the way is open to record sets of Mode 3 data in parallel with routine surveys. These data could be used as scheduled periodic adjuncts to survey data or could be focused on selected sites for potential enhancements to the science eventually to be derived from the data.

Sampling Strategy

Approximately 10^{10} bits can be telemetered to Earth during the course of Europa Orbiter's nominal mission, and much of this downlink will be devoted to optical imaging and other experiments. Europa can be completely mapped at full resolution by a radar sounding system with only 10^9 bits, assuming 16-bit data encoding and 2:1 lossless compression. This could be achieved in just over a week of operation with a 50% duty cycle. The ability of the radar to function on the night side of the satellite adds flexibility to its operation and allows mapping to be conducted within the available spacecraft power resources and processing capability.

Two other types of data products in addition to this primary sounding data may be desirable. First, samples of the unprocessed data should be acquired to characterize the permittivity of the Europan subsurface as a function of depth and to tune the operation of the instrument early in the mission. Downlink constraints dictate that only a few such samples can be

acquired. At a minimum, equatorial and polar regions of Europa should both be studied and efforts made to examine the major geologic terrain types on the satellite such as ridged plains, chaotic terrain and impact structures.

Second, global mapping at reduced resolution should be undertaken. Sounding data at one-tenth resolution could be acquired over extended periods and stored on board the spacecraft for later telemetry. The radar can serve as a coarse altimeter, providing positional information to augment the geodetic experiments. The total data volume generated by these activities amounts to no more than a quarter of the primary full resolution mapping data set, but greatly enhances the scientific return from the investigation.

2.1.4.4 Imaging System

The strawman imaging system consists of two framing cameras having two different fields of view. Both use charge-injection device (CID) detectors because of their radiation hardness. Protective covers and purge subsystems are included to prevent contamination in the Shuttle. A 10-W heater is provided for each camera for contamination control purposes during cruise, if power is available.

The high-resolution narrow-angle camera (NAC) optics have a 10-cm focal length and operate at f/4. Its detector is a 1024x1024 array of 7.5-µm pixels with a pixel pitch of 10 µm yielding a pixel angular size of 100 µrad and a total FOV of 100 mrad. No spectral filtering is included. The estimated mass is 1.13 kg, and the average power is 0.1 w (0.3 w peak). Volume is estimated at 15x5x5 cm. The pixel IFOV generates a 20-m footprint from 200 km altitude. Keeping image smear to <0.5 pixel requires exposure times <7.5 msec for the ground speed of a 200-km orbit for a nadir view without any spacecraft motion compensation. Contiguous coverage along the ground track from 200 km altitude requires frames to be acquired about every 14 seconds. To minimize radiation-induced noise in the images, frames should be read off the detector as fast as possible (10^6 pixels/sec or faster). Encoding to 10 bits/pixel results in a raw output data rate of 10 Mbps into a temporary frame buffer. Data compression at 2.5:1 is included in the strawman resulting in a data storage volume of 4.2 Mb/frame.

The wide-angle camera (WAC) optics have a 1-cm focal length and also operate at f/4. Its detector is a 256x256 array with the same pixel size and pitch as the NAC. The pixel angular size is 1 mrad, and the total FOV is 0.26 radian. A 4-color filter wheel is included. The estimated mass is 1.53 kg, and the average power is 3.1 w (3.3 w peak). The major power consumer is the filter wheel mechanism. Volume is estimated at 4x4x6 cm. The pixel footprint from 200 km is 200 m. Exposure times up to 75 msec can be used while keeping smear to <0.5 pixel. This should allow spectral filters as narrow as about 100 nm to be used with adequate signal to noise. Contiguous coverage along the ground track from 200 km

altitude can be obtained with images acquired about every 36 seconds; 4-color coverage would require images every 9 seconds. Readout at 10 Mbps into a temporary frame buffer followed by data compression at 2.5:1 results in a data storage requirement of 0.26 Mb/frame. Imaging every 9 seconds yields a data rate to the data storage memory of 29 kbps. Contiguous color imaging while on the sunlit side for two orbits would generate a total WAC data storage requirement of 241 Mb.

An alternative approach for the WAC that could have some distinct advantages is to use a pushbroom imager rather than the framing camera assumed as a strawman; this approach would allow color imaging without the power-hungry filter wheel mechanism but has disadvantages in the areas of geometric image reconstruction and lack of commonality with NAC hardware.

Radiation concerns must be addressed for optical elements as well as for the detectors and electronics.

2.2   Description Of Spacecraft Concept And Mission

2.2.1   Reference Mission

2.2.1.1   Launch/Interplanetary Trajectory

The Europa Orbiter reference mission calls for an STS/IUS/Star48V launch in November 2003. The spacecraft will take a direct trajectory to Jupiter (see Figure 6), arriving between August 2006 and August 2007 (depending on launch date).

The opportunity to switch the launch order of Pluto/Kuiper Express (PKE) and Europa Orbiter (EO), however, is a key requirement of the program readiness strategy. If the option to switch the order of the PKE and EO launches is exercised, the PKE launch would be moved up to November 2003, and EO would move into the December 2004 slot. Arrival would be proportionately later, of course.

2.2.1.2   Jupiter Arrival

Upon arrival into the Jupiter system (see Figure 7), EO will get an inbound gravity assist from Ganymede just prior to the Jupiter Orbit Insertion (JOI) burn of up to 1000 m/s. JOI will target the spacecraft for a roughly 200-day initial orbit about Jupiter (see Figure 8), which after a small perijove raise maneuver, will return to Ganymede (G1).
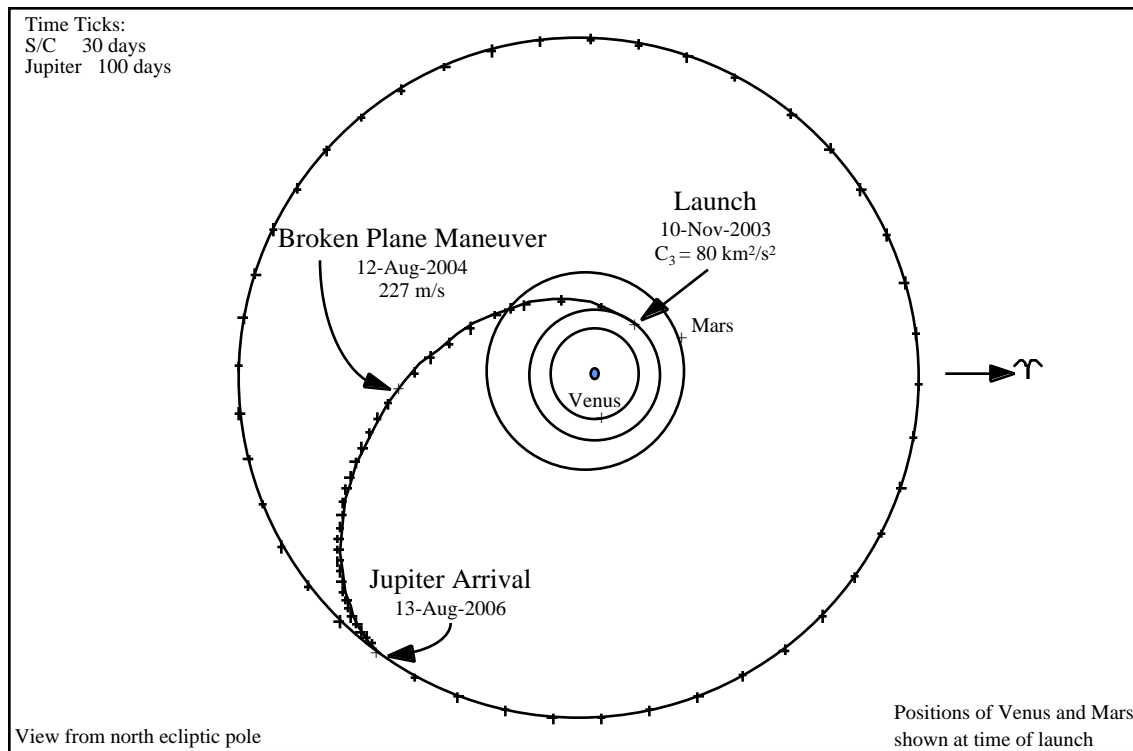
Figure 6. Europa Orbiter 2003 direct trajectory

2.2.1.3 Tour/Endgame

A Galileo-like tour of the satellites Europa, Ganymede, and Callisto will begin with G1 (see Figure 9) and is nearly ballistic. It will take at least a year from arrival at Jupiter to get the spacecraft to the beginning of what is called the Endgame, which is the part of the trajectory during which the spacecraft will use only Europa flybys and large propulsive maneuvers to achieve the desired final approach to Europa (see Figure 10). The primary goal of the tour/endgame is to minimize delta-V in reaching a high-inclination orbit about Europa. Secondary goals are to keep the total radiation dose to <2 Mrads and the duration from JOI to EOI to <3 years.

The roughly half-dozen Europa flybys which constitute the Endgame will exhibit more or less the same spacecraft/Europa geometry because the spacecraft orbit will be in near-resonance with Europa's orbital period and, therefore, must encounter Europa at about the same point in its orbit each time. Satellite flyby altitudes are expected to range between 100 and 10,000 km. The Endgame is expected to take about 3 months and culminates in a ballistic capture of the
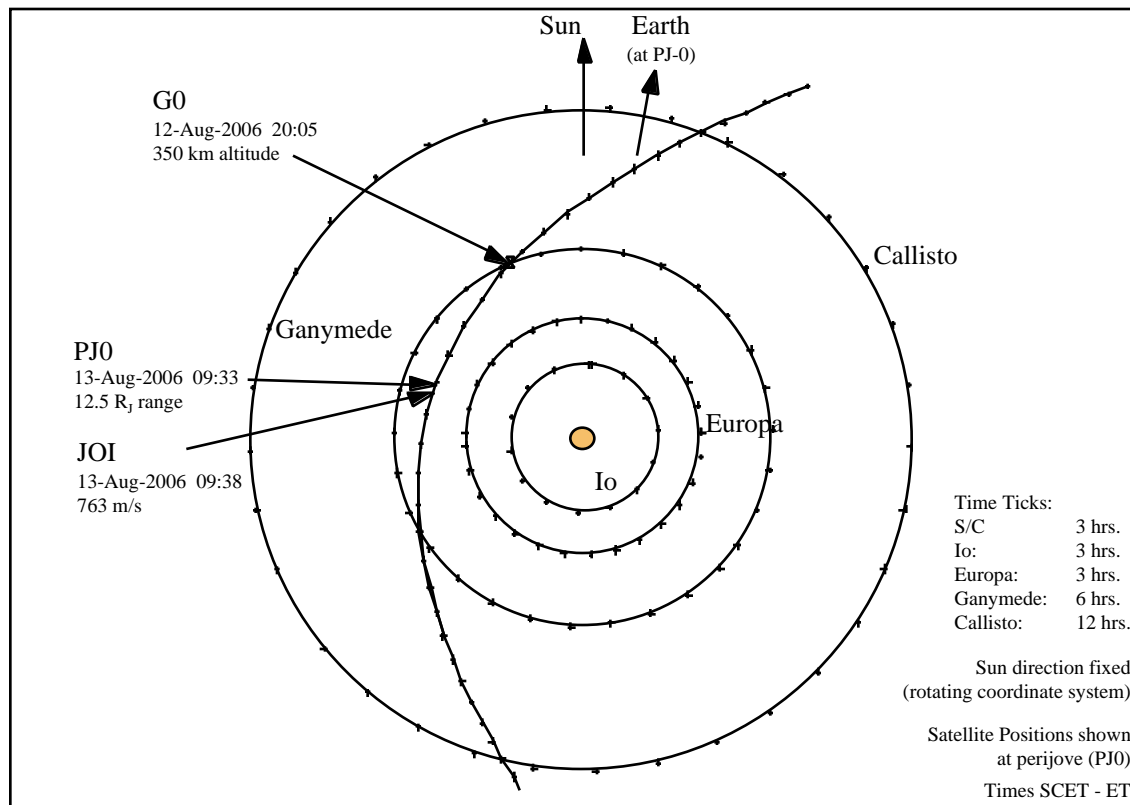
Figure 7.   Europa Orbiter - Jupiter arrival geometry.

spacecraft by Europa. Preliminary estimates put the total radiation dose for the endgame at about 2 Mrads, half of the mission total of 4 Mrads (behind 100 mils of Al), the other half coming during the 30-day primary mission around Europa.

2.2.1.4   Europa Orbit

A large, >500 m/s burn, will put the spacecraft into a low-eccentricity interim orbit from which the gravity field mapping experiment can begin (the current reference periapsis altitude is 200 km, although the actual value is subject to future analysis/negotiation). The eccentricity of the interim orbit around Europa, and the duration of stay in that orbit, will be dependent on orbit-stability and gravity-science studies that will be conducted in the Project's development phase. The gravity field mapping requires different orbits to help separate the small atmospheric effects from the gravity field signature and also the higher order gravity harmonics from each other. By "walking down" the initial apoapsis, it is believed that this
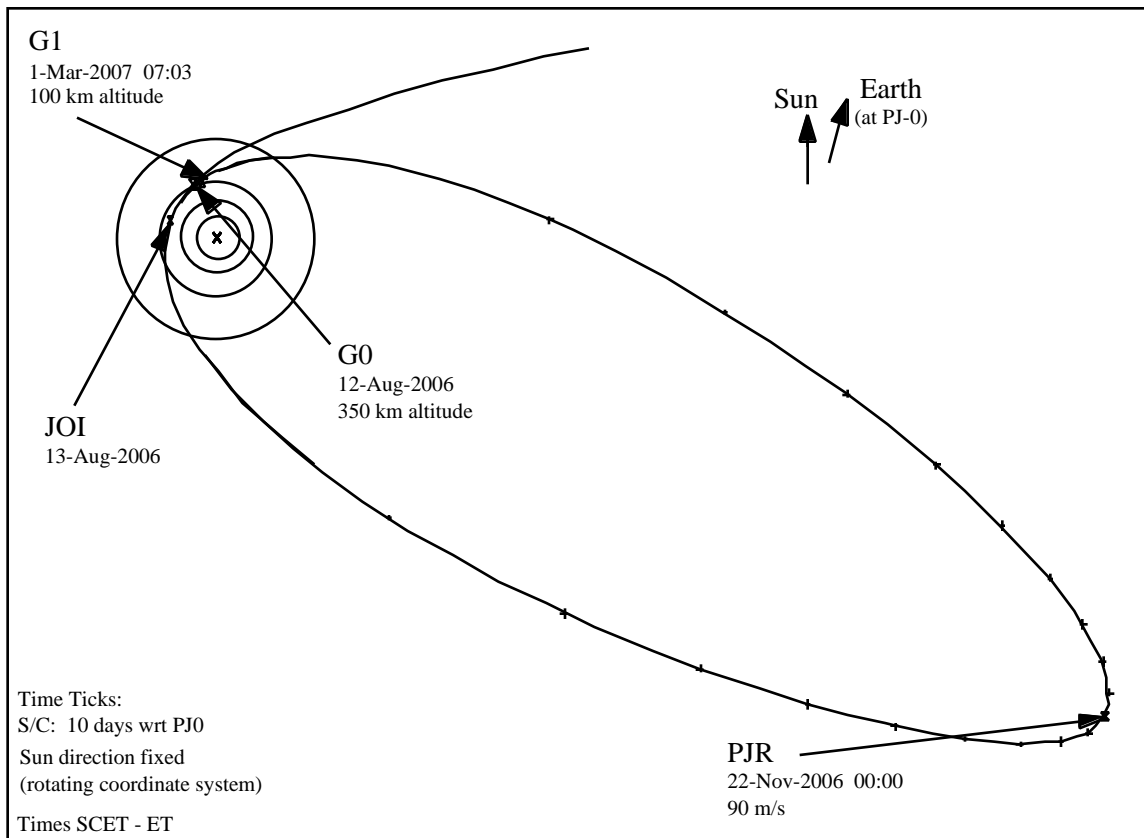
Figure 8.   Initial Jupiter orbit

requirement can be met at no significant additional delta-V cost (in fact, it may reduce finite burn losses of the orbit insertion). There is no specific allocation of delta-V for an altitude change once in close Europa orbit, although 20 m/s is allocated for orbit control over the 30-day mission. This allocation is sufficient to maintain altitude control within a ±10-km range.

Table 4 includes a summary of the range of key parameters describing the final mapping orbit around Europa.

After the appropriate length stay in the initial eccentric orbit, the spacecraft will circularize its orbit at 100-200 km altitude (as indicated above, 200 km is the current reference; future studies will determine the final altitude). Figure 11 shows a typical groundtrack on Europa for a 200 km altitude, 75 degree inclination orbit. There is no current plan to maintain a repeating ground track.
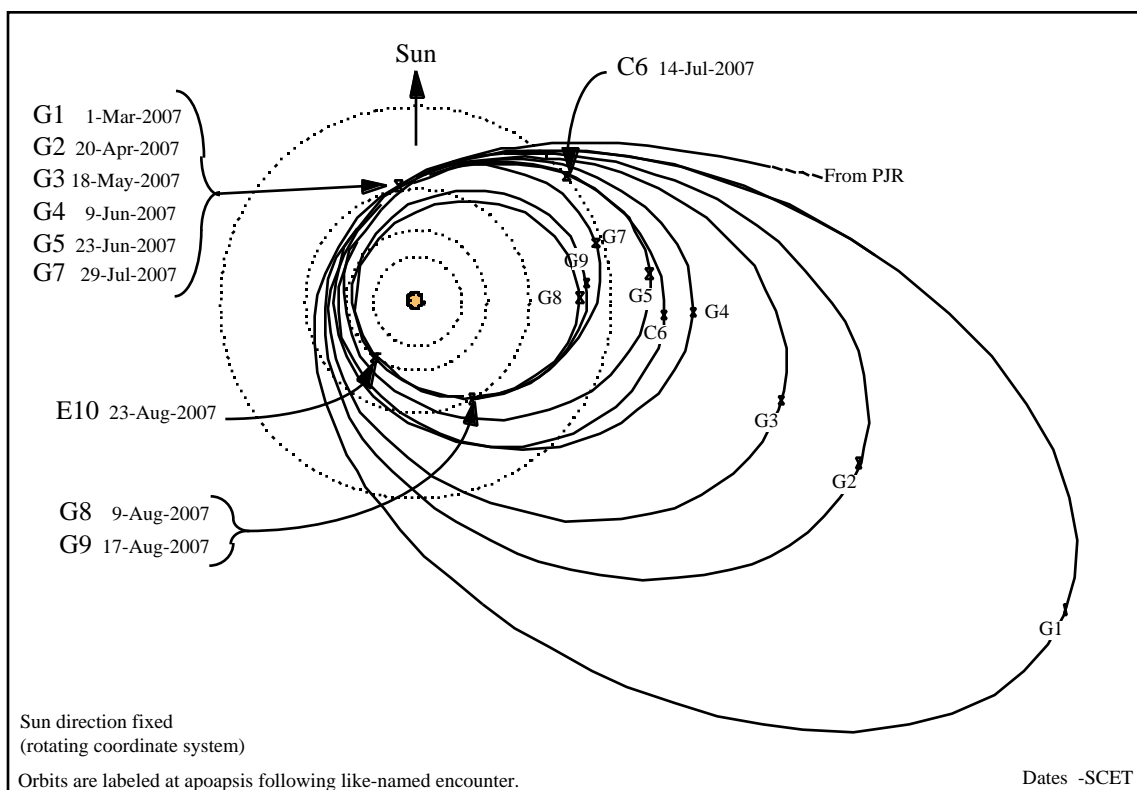
Figure 9.   Representative Europa Orbiter satellite tour trajectory

Table 4.   Range of potential Europa final mapping orbit parameters

Parameter	Reference	Likely Range
Altitude (km)	200	100 - 200
Period (min)	138	126 - 138
Inclination (degrees)	83	70 - 88
Line of nodes	Ascending node = 310 degrees*	• 10 degrees < Earth/Europa/node angle < 80 degrees • Within 20 - 50 degrees of solar meridian
Eccentricity	0.0	0.0 - 0.1

*   Defined here as the angle measured clockwise from the solar meridian when viewing southward (from Europa's north pole) to the spacecraft's ascending node.

C-25
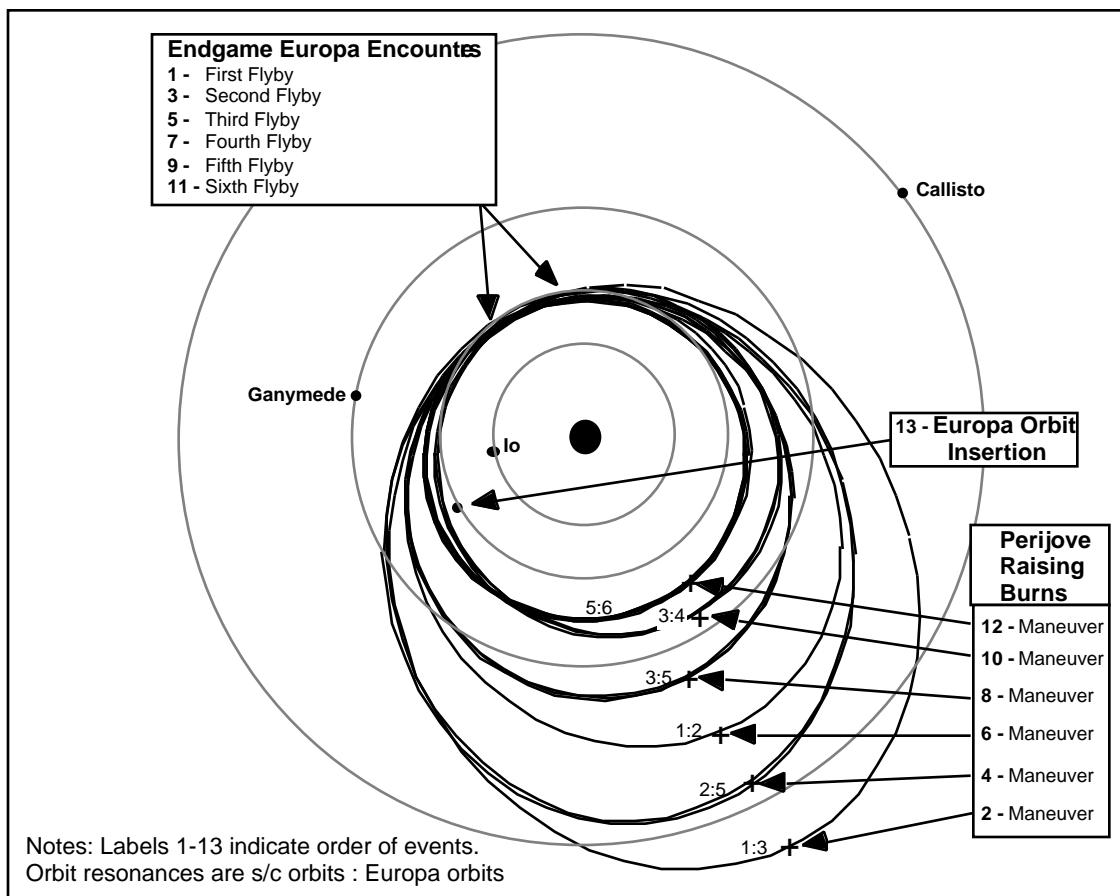
Figure 10. Europa Orbiter endgame trajectory

2.2.1.5   Europa Orbit Science Mission Design

Figure 12 shows one example of how the orbital operations might be conducted in Europan orbit within the scope of the available resources. It is important to note that the chosen science team is expected to be intimately involved in the design of the actual orbital operations. Additionally, some key constraints that must be observed in the actual sequence are accommodated in the example. The most important of these is that there is not sufficient power to operate all of the instruments simultaneously. Another, geometrical consideration is the once-per-eurosol (Europan day) eclipse and Earth occultation by Jupiter for as much as 3.5 hours. Spacecraft reaction wheel momentum dumps will be required at least every 3 days and possibly daily.
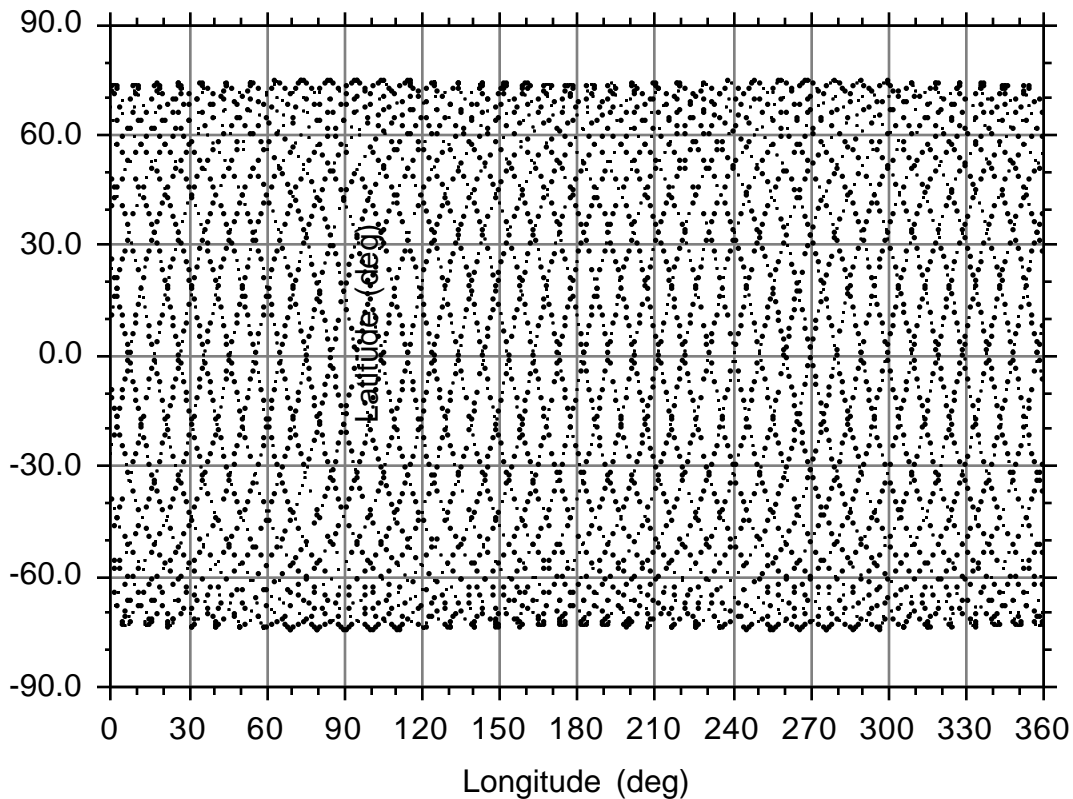
Figure 11. Europa Orbiter ground track (alt = 200 km, i = 75°) -- Europa J_2 and 3rd body effects included. Time span ~3.5 days (near-repeat period).

It is envisioned that the interim orbit will provide an opportunity for initial characterization and initial orbital science from all instruments. A to-be-determined duty cycle of nadir-pointed data acquisition and Earth-pointed data downlink will take place during the interim orbit.

Following circularization in the mapping orbit, the mission will enter the gravity/altimetry phase for two eurosols. Figure 12 shows a preliminary 37:1 duty cycle between nadir-pointed orbits to Earth-pointed downlink orbits during this phase, during which the medium-gain antenna (MGA) will be the primary method of acquiring tracking data while nadir pointed. This duty cycle is primarily driven by the desire to minimize subsurface forces on the spacecraft that might be associated with turning the spacecraft and to maximize tracking time. Insufficient power is available over the MGA link to support telemetry.

The radar/imaging phase of the mission follows the gravity/altimetry phase and will take about 5 eurosols to complete at the expected duty cycle of 2:8 between nadir-pointed orbits to Earth-pointed downlink orbits. This average duty cycle is driven primarily by downlink capability. It is expected that the spacecraft transmitter will be turned off during the nadir-pointed science data gathering orbits of this phase to allow sufficient power to be available for the instruments.

If there is sufficient propellant left after the radar/imaging phase, an orbit altitude lowering may be possible to enable selected high-resolution data taking for all investigations. There are no current plans for any extended mission operations.
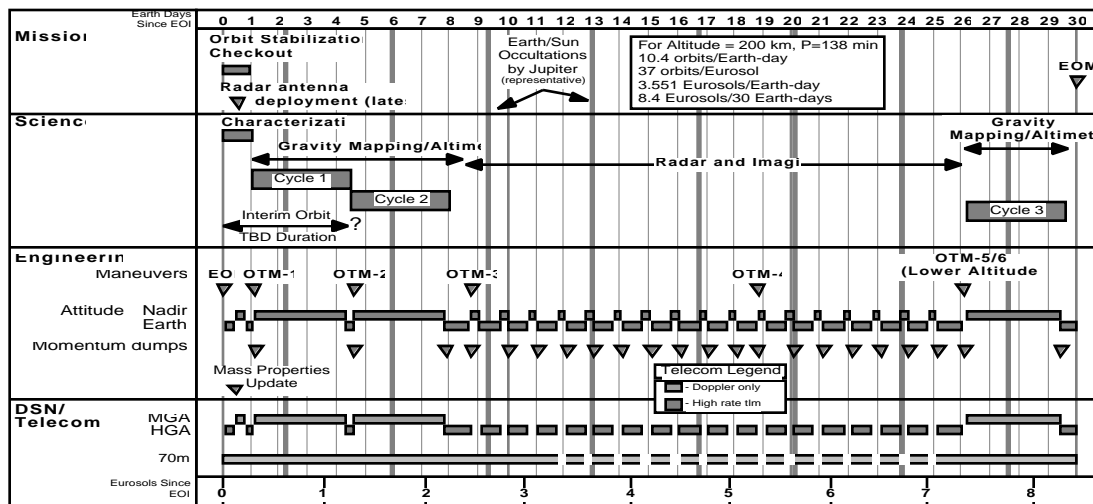
Figure 12. Europa Orbiter sample prime mission overview (Europa orbit phase)

2.2.1.6 Orbit Determination Accuracy

It is expected that, once in Europan orbit, there will be some tracking data available on a daily basis. In the first few days of Europa orbital operations, the one-sigma orbital uncertainties projected a few days into the future (for use in observation sequencing) will be of the order of 0.5-2 km in the radial and crosstrack directions and perhaps an order of magnitude worse in the downtrack direction. These uncertainties will diminish rapidly as the Europan gravity field is determined, and the accuracy of predicting the spacecraft's position a few days in the future will be improved by about a factor of 10. The contribution of orbit prediction errors to pointing control error will thus remain no smaller than about 10 mrad along track and 1 mrad crosstrack (one sigma). Post-mission reconstruction of the orbit is expected to approach 1m in the radial direction and 10's of meters in crosstrack and downtrack, one sigma.

2.2.2   Spacecraft System Design

2.2.2.1   Applicable Standards

The following standards apply:

- The metric system of measurement
- X2000 Mission Data System standards for software implementation
- Reliability, Quality Control, and Safety standards will be tailored to the mission with specific emphasis as appropriate for a long, but cost-capped, mission and in accordance with the project risk management approach

2.2.2.2   System Overview

The flight system for the reference mission is envisioned to consist of a 3-axis stabilized spacecraft bus that houses the engineering and science electronic subsystems, a high-gain antenna subsystem, a propulsion module, and a proposed Advanced Radioisotope Power Source (ARPS). The actual spacecraft power source is yet to be defined; however, the ARPS creates the most challenging radiation environment to which the science payload should be designed. A view of the spacecraft concept is shown in Figure 13. Instruments are fixed mounted to the spacecraft; there is no instrument pointing platform provided. Instrument pointing is accomplished by maneuvering the entire spacecraft.

The major hardware elements are depicted in Figure 14.

The current approach assumes that a substantial portion of the engineering subsystems will be designed and qualified through the JPL technology development program, X2000. The electronics design will incorporate advanced technologies to allow integration of several functions onto a single substrate. By decreasing the size of the electronics while increasing functionality, the electronics mass will be significantly decreased for the Europa Orbiter mission as compared to previous missions. The integration of the electronics into a small volume will also reduce the mass of the cabling required to integrate these functions. Additionally, the majority of the electronics developed by X2000 will be radiation hardened to 1 Mrad, and, therefore, less additional shielding mass will be required to meet the 4-Mrad requirement for Europa Orbiter.

Since X2000 is just getting started and has a very aggressive program, some of their deliverable products may not have the performance envisioned today. Whenever possible, this has been foreseen in this AO by the science allocations identified. As X2000 matures and the final flight performance and components are determined, the flight system and instruments will
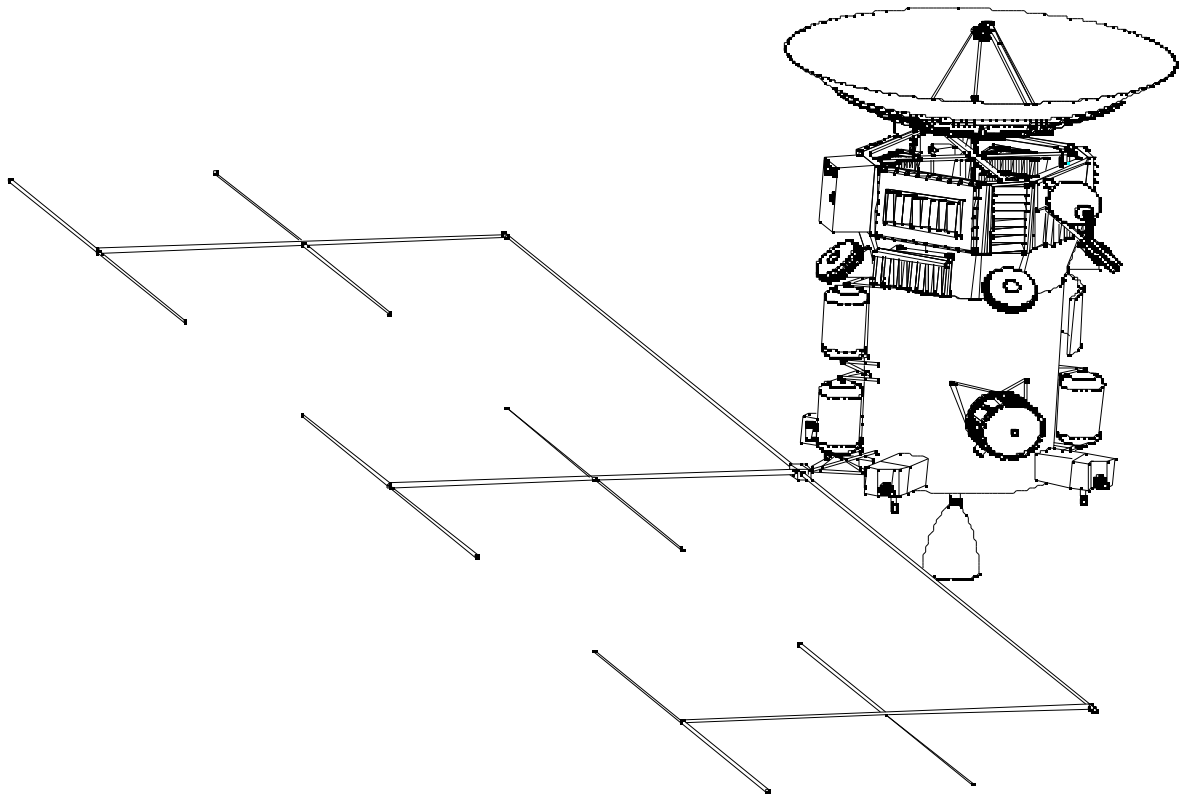
Figure 13.   Europa Orbiter spacecraft with Yagi radar antenna deployed

need to review and finalize the functions and capabilities to be flown. The approach assumed for the integration of the science payload into the engineering system is to minimize the duplication of function and, thereby, allow maximum science return for the minimum mass and power. To achieve this, an integrated team will need to determine the final distribution of functions between the science payload and the engineering system. Concurrent engineering and teamwork will be required to ensure that the science objectives are met within the resource constraints of the mission. However, for the purposes of this proposal, the allocations of resources and functions to the science payload specified herein should be assumed.

2.2.2.3   Mass

The mass of the total science payload exclusive of the consortium radar instrument shall be within the allocation shown in Table 6 (Sec 3.A) including any radiation shielding and reserves.

Figure 14.   Europa Orbiter functional block diagram.

2.2.2.4   Power

The average power allocated for nonradar science is shown in Table 6 (Sec 3.A). This allocation is a maximum for any given point in time during the mission except for possible short-term contamination prevention. The peak power for the total nonradar science complement may exceed this number, as long as, operationally, the science observations are sequenced so that an average of no more than the allocation is required over any extended period of time. Power transients up to 100 W for   50 msec are acceptable.

The spacecraft will supply regulated 28 ± 2 VDC power to the science instruments. Any high-voltage requirements will be the responsibility of the science investigation. Telemetry will be available on all switched power lines.

2.2.2.5   Volume

The volume allocated to the Europa science instruments is broken into two sets: externally mounted optical instruments and internal bus instruments (optical instrument electronics not housed with optics, etc.).

The volume allocated to the externally mounted optical instrument package(s) is 225 mm x 400 mm x 350 mm, where the mounting interface is 225 mm x 400 mm. The aperture plane can be located on either the 400 mm x 350 mm plane, which is perpendicular to the mounting plane, or on the 225 mm x 400 mm plane parallel to the mounting plane. Radiators can also be located on either of these planes, although the best field of view to space will be on the plane parallel to the mounting plane.

The volume allocated to the internal bus instruments is a 400 mm x 400 mm x 120 mm. Half of this volume is available for the optical instrument electronics that may be housed internally. Although this area can be subdivided, the preference is for all science hardware mounted internally to the bus to be kept in one location.

2.2.2.6   Thermal

All instrument hardware located internally to the bus shall be capable of an allowable flight operating and nonoperating temperature range of -20°C to +50°C.

For the externally mounted optical instrument(s), the panel interface temperature range is -20°C to +50°C. All thermal dissipation within the external optical instrument package(s) must be dissipated to space from the instrument housing(s) or radiators. Low-temperature radiators for the optical sensors are probably best located on the plane parallel to the mounting plane (if the apertures are also in this plane, the thermal impact of viewing Europa must be compared with the poorer FOV to space on another side). Radiators in any plane are not guaranteed a 100% hemispherical field of view to space (see Section 2.2.2.h).

Any science instrument radiators or temperature-control electrical heaters or coolers necessary for conducting the science investigation are the responsibility of the science investigation. Instruments will be responsible for temperature sensors and heater switches related to the operational performance requirements. The Project will supply temperature sensors and

heater switches related to maintaining the instrument within allowable flight temperatures or providing decontamination.

In addition to electrical power, the ARPS thermal dissipation could be utilized to heat the propulsion subsystem. In addition to this waste heat, the spacecraft may utilize Radioisotope Heater Units (RHU's), electrical heaters, louvers, radiators, and thermal blankets for temperature control throughout the spacecraft, including the bus (see Section 2.2.2.l below).

The spacecraft thermal design will be capable of maintaining the propulsion subsystem within a 5°C and 50°C temperature range and the bus within a -20°C and 50°C temperature range throughout the mission. The current direct mission trajectory encompasses a solar range of 1 to 5.2 AU.

2.2.2.7   Command, Control, and Data

The spacecraft data subsystem is being developed by the X2000 program and is centered around 2 system flight computers (SFC) shared between engineering and science tasks, such as data processing, editing, compression, etc.

The SFC will control one redundant high-speed and one redundant low-speed data bus. The protocol standard for the high-speed bus is IEEE 1394. The protocol standard for the low-speed data bus is I^2C. The I^2C bus is used for configuration purposes and science instrument commanding.

A generic microcontroller will serve as the standard interface between the data buses and remote terminals such as instruments. Each microcontroller will provide interfaces to the four data buses: prime high-speed, backup high-speed, prime low-speed, backup low-speed. Two microcontrollers will be supplied by the spacecraft for use by the remote sensing instrument package. Their characteristics are defined below and in the "Description Of X2000 Components Available For Use In Instrument Proposals" document of the Outer Planets Program Library, available over the Internet through URL http://outerplanets.LaRC.NASA.gov/outerplanets. The mass, power, and cost for these microcontrollers need not be covered within the payload resource allocations of Table 6 in Section 3.1. Any science data processing software that runs on the microcontrollers or the SFC must be supplied and budgeted by the science investigation, however.

Since data acquisition and data downlink cannot, in general, occur simultaneously due to mutually exclusive pointing requirements, the spacecraft data subsystem will include bulk data storage. The current baseline design employs nonvolatile flash memory (NVM).

The planned software operating system for the spacecraft is VxWorks. The planned programming language is C^{++}.

The spacecraft will provide time distribution across the command bus with an accuracy of to-be-determined (expected value = 30) msec relative to the spacecraft clock. The instruments can use this to time tag their data when its packet is sent to the spacecraft data system. Otherwise, the spacecraft will time tag the payload packets when received by the data system within to-be-determined (expected value = 30) msec. Each downlink frame is time-tagged to 30 msec relative to spacecraft clock at the time the frame is put together by the data system.

Tentative key requirements for the total data subsystem are:

System processor speed	30 MIPS
High-rate bus bandwidth	100 Mb/s
Low-rate bus bandwidth	100 kb/s
Data storage	up to 6 Gbits

Microcontroller characteristics:

speed	10 MIPS
8-bit parallel ports	4
UART ports	2
UART speed	1.5 Mb/s
PCI bus interfaces	1
I^2C subnet	2

Only a fraction of the data subsystem capabilities defined above will be available to support science tasks as reflected in the resource allocations of Table 6 in Section 3.1.

2.2.2.8   Fields of View

The stray-light field of view (FOV) for the optical instrument boresights is a minimum of 30˚ half angle from nominal. Hardware at the edge of the 30˚ stray light FOV includes the HGA, thermal blankets, and possibly louver assemblies for apertures in a plane perpendicular to the mounting plane. Since materials for these items are still to be determined, worst-case surface optical properties are to be assumed. This worst-case corresponds to apertures in a plane perpendicular to the mounting plane. For apertures in the plane parallel to the mounting plane, the FOV will be greater.

For optical instrument radiators, the FOV at the mounting plane is a minimum of 30° in any direction. As a radiator surface moves away from the mounting plane, the FOV angle increases. At approximately 350 mm from the mounting surface, the FOV in the current configuration is approximately 60° to 70° in the worst case directions (namely the HGA above and propulsion system blankets below). The surfaces that the radiators will see under operating conditions at Europa are the HGA, thermal blankets, and potentially louver assemblies, if mounted perpendicular to the mounting plane. Although the surface temperatures of these items are extremely cold at Europa, any cryogenic (100 K or less) radiators will be impacted and should be shielded/sized accordingly. Radiators in the 180 K range will have only minor impacts. Since materials for these items are still to be determined, worst-case thermo-optical properties are to be assumed.

2.2.2.9 Coordinate System and Mechanical Design

The flight system configuration, shown in Figure 13, consists of the High Gain Antenna (HGA) assembly, the Science and Avionics Module (SAM), and the propulsion subsystem (PROP). The HGA assembly includes a 2-m reflector, the feed and secondary structure, and may provide the sun sensor mounting interface. The antenna will most likely consist of a composite structure. As the telecom system is further defined, the size of the antenna may be modified.

The spacecraft coordinate system is as shown in Figure 15. The spacecraft Z axis is located through the centerline of the spacecraft with +Z in the main engine nozzle direction. The X-Y plane intersects the Z axis at the interface between the bus/upper shell structure and the propulsion subsystem and oriented with +X in the direction of the instrument boresights.

The SAM houses all of the science equipment (with the possible exception of the Radar antenna) and all of the spacecraft avionics. The four large flat sides of the SAM are referred to as the bus shear plates. These shear plates are where most of the internal bus hardware will be located. The four smaller sides of the SAM are referred to as the frame panels and provide the frame for mounting the shear plates. External bus hardware is ideally mounted on the frame panels, while internal bus hardware can be mounted to the frame panels as needed. The adapter structure seen below the bus provides the transition from the 8-sided bus to the circular interface of the propulsion system. The adapter also provides additional mounting surface for hardware mounted outside the bus. This entire assembly (shear plates, frame panel, and adapter) comprises the Science and Avionics Module (SAM) structure. The shear plates are anticipated to be made of aluminum. The frame panels and adapter may be made of either aluminum, honeycomb, or composite.
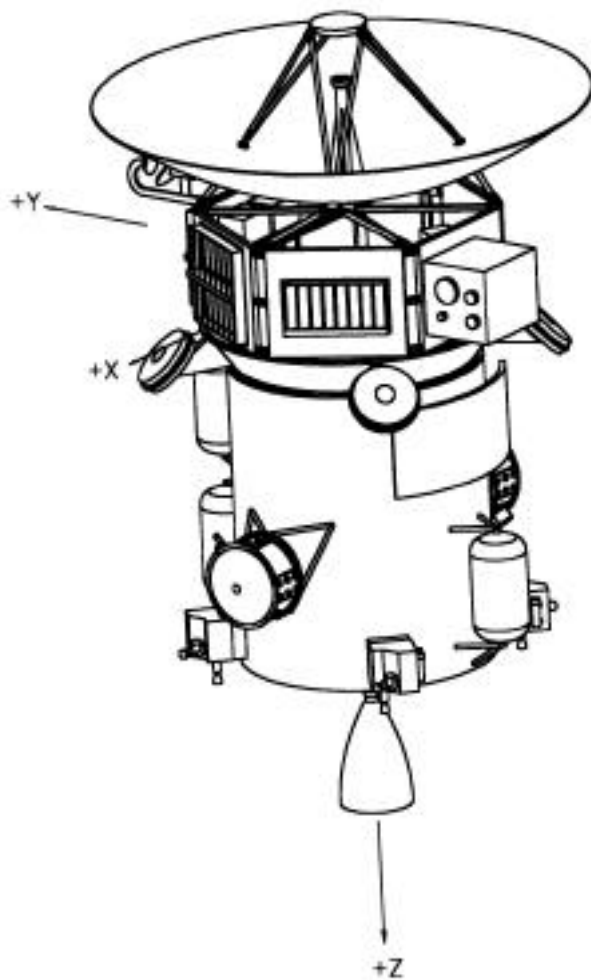
Figure 15.   Europa Orbiter spacecraft coordinate system

The optical package is anticipated to be mounted to a frame panel. Figure 16 shows the apertures on the plane parallel to the mounting interface. Although this currently appears to be the most favorable direction for the current spacecraft configuration, this direction is not required. Please note that radiators are not depicted in the optical package cartoon shown in Figure 16. Any electronics for the optical package that are mounted internally to the bus would be located on a shear plate adjacent to the optical package. An articulating medium-gain antenna (MGA) (or fixed MGA with an articulating reflector) will also be located on the SAM. It will allow simultaneous optical pointing at Europa with ranging and Doppler tracking of the spacecraft.

Remote Sensing Package

Science Electronics (including Radar and Remote Sensing)

Remote Sensing Package
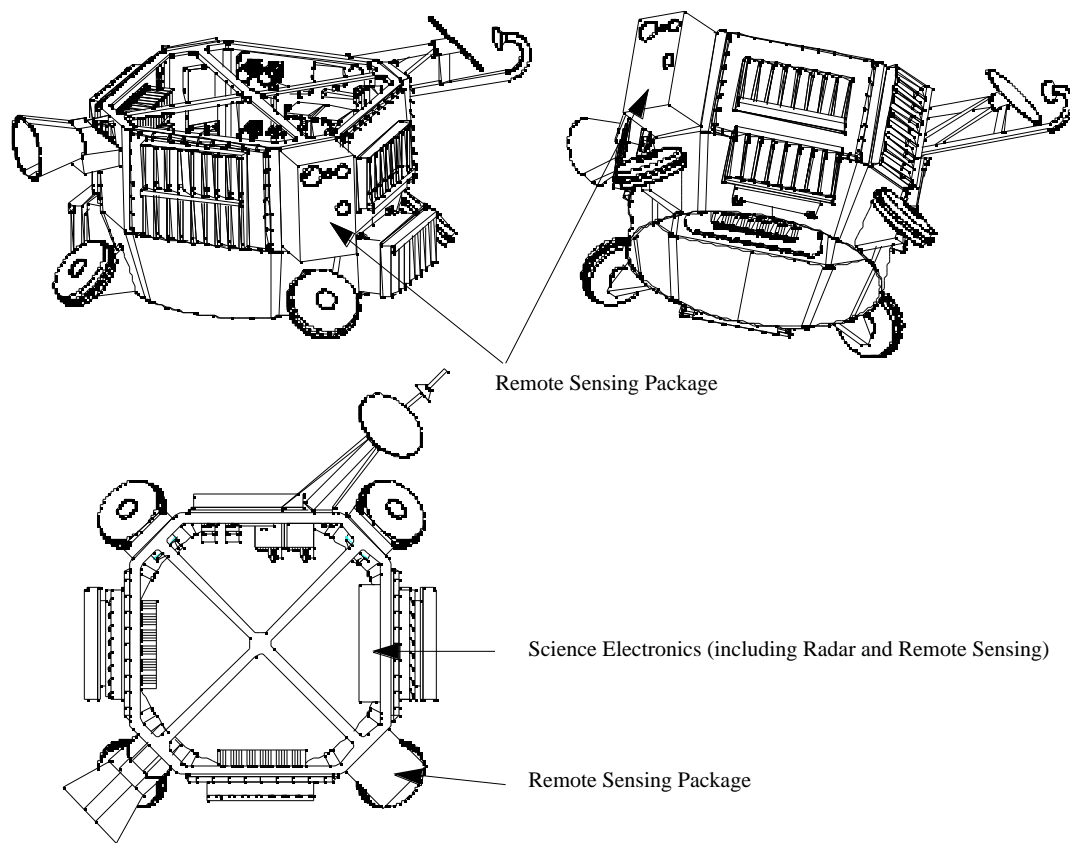
Figure 16.   Europa Orbiter Science and Avionics Module (SAM)

Below the bus is the propulsion subsystem. The system depicted in Figure 15 is only a strawman concept and is subject to significant change once a propulsion system contractor is chosen. The current strawman propulsion subsystem is a dual-mode system consisting of a single hydrazine fuel tank and a single NTO oxidizer tank. These tanks are structurally mounted inside a cylindrical core structure. This core structure also supports all of the propulsion components, the high pressure helium tanks, and the Advanced Radioisotope Power Source (ARPS).

The flight spacecraft utilizes a linear pyro separation assembly between the base of the propulsion subsystem and the launch vehicle adapter. The main spacecraft load path flows from the bus frame and upper shell structure, through the core propulsion structure and linear separation assembly, to the launch vehicle adapter.

2.2.2.10 Attitude Control

Attitude determination will be done using star trackers, gyros, and a sun sensor. Gyros will be part of a package that includes an accelerometer to measure spacecraft delta-V in a single axis. Attitude control will be accomplished using reaction wheels.

Additional functions of the spacecraft attitude control subsystem are to navigate and control the Star 48V injection kick motor. Roll control during injection will be provided by the spacecraft.

Fine pointing will be accomplished using the star tracker for attitude knowledge. Nearly continuous attitude estimation is planned. The star tracker is required to provide full 3-axis attitude determination.

The gyros will be used principally for maneuvers. The sun sensor will be used principally for attitude acquisition during cruise and faults.

Key baseline capabilities for the overall attitude control subsystem are:

pointing accuracy	7 mrad
pointing knowledge	3 mrad
pointing stability	1 mrad in 1 sec
	20 µrad/s in 10 msec
maximum slew rate	1.5 mrad/s

Some to-be-determined settling time will be required after fast slews before reaching the final stability level.   In developing science observing sequences, adequate time must be allocated to reorient the spacecraft before and after data downlinking and reaction wheel desaturation sessions. Such maneuvers could take on the order of 30 minutes to execute.

2.2.2.11 Telecommunications

The telecom subsystem for the Europa Orbiter reference mission consists of a 2.0-meter high-gain antenna, a dual-power 20- and 5-Watt RF X-band Solid State Power Amplifier (SSPA), and block-redundant Small Deep Space Transponders (SDST's). A top-level diagram showing the telecom subsystem architecture is shown in Figure 17.

A medium-gain antenna consisting of a fixed feed and a steerable reflective mirror provides the capability for Doppler tracking while keeping the instruments nadir pointed in Europa orbit but does not support telemetry.

The telecommunications configuration shown is a unified uplink/downlink X-band design such that all telecom link functions can be utilized simultaneously.

  Command
  Telemetry
  Doppler Tracking
  Ranging

Since both the DSN and flight system have constant power transmitters, the division of power between simultaneous links will vary depending on specific link configurations. This will affect link performance when supporting multiple links at once. Key communications parameters for the Europa Orbiter mission at 5.2 AU are listed in the table below.

Parameter	Europa Orbiter		Units
Transmitter Power	20	5	Watts
High Gain Antenna	40	40	dBi-RCP
Medium Gain Antenna	15	15	dBi-RCP
Science Uplink Command Rate	2	2	bps
Typical DSN Lockup Time	5	5	min
HGA Downlink rate (max)	100	25	kbps

Downlink rate assumes 70-m DSN antenna at 20º elevation angle and 90% weather. Uplink command rate assumes 70-m DSN transmitting at 20 kW to the HGA and represents the effective transmission rate for science commands (the actual bit rate sent to the spacecraft is substantially higher).

2.2.2.12 Propulsion

The propulsion subsystem will provide the required onboard incremental changes in velocity and reaction attitude control capability for the spacecraft over the lifetime of the mission. The total propulsive delta-V requirement is baselined at 2447 m/s, with a major driver being the requirement to achieve orbit about Europa. The propulsion subsystem is a dual-mode system. JOI and Jupiter maneuvers, including those of the Europa endgame, use the 450-N main engine, which uses NTO and purified hydrazine. Cruise, on-orbit maneuvers, and reaction wheel desaturations use smaller (12 to 22 N) thrusters and purified hydrazine. The system is pressurized with helium, but the main engine mixture control is managed with Variable Liquid Regulators.
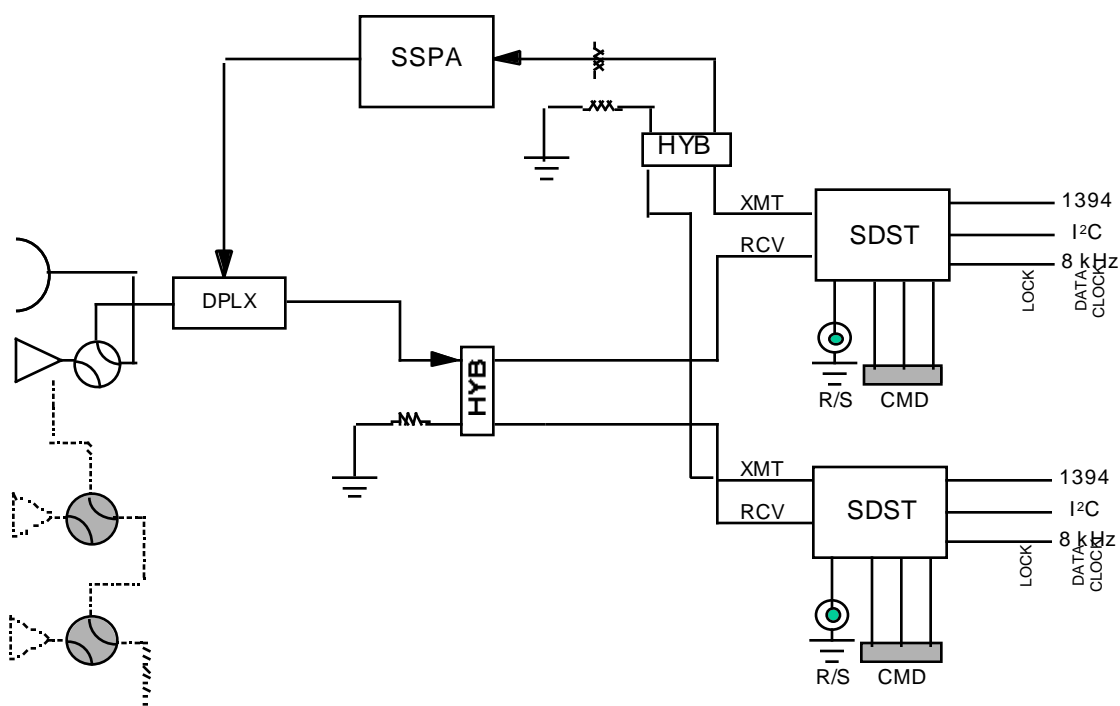
Figure 17.   Europa Orbiter telecomm system architecture

    2.2.3   Launch Vehicle

        2.2.3.1   Launch Site

The expected launch site will be either NASA Kennedy Space Center or the U.S. Air Force
Cape Canaveral Station, Florida, USA.

        2.2.3.2   Launch Vehicle

The final launch vehicle selection has not yet been made. The reference mission assumes that
the Europa Orbiter spacecraft will be designed for launch on the STS/IUS/Star48V launch
system. Europa Orbiter will utilize a Jupiter-direct trajectory with a flight time of about 3
years to Jupiter.

2.2.4　Environmental Requirements

Figure 18 shows the best estimate of the integral dust particle fluence on the Europa Orbiter spacecraft over the entire mission.

Europa Orbiter Dust Fluence
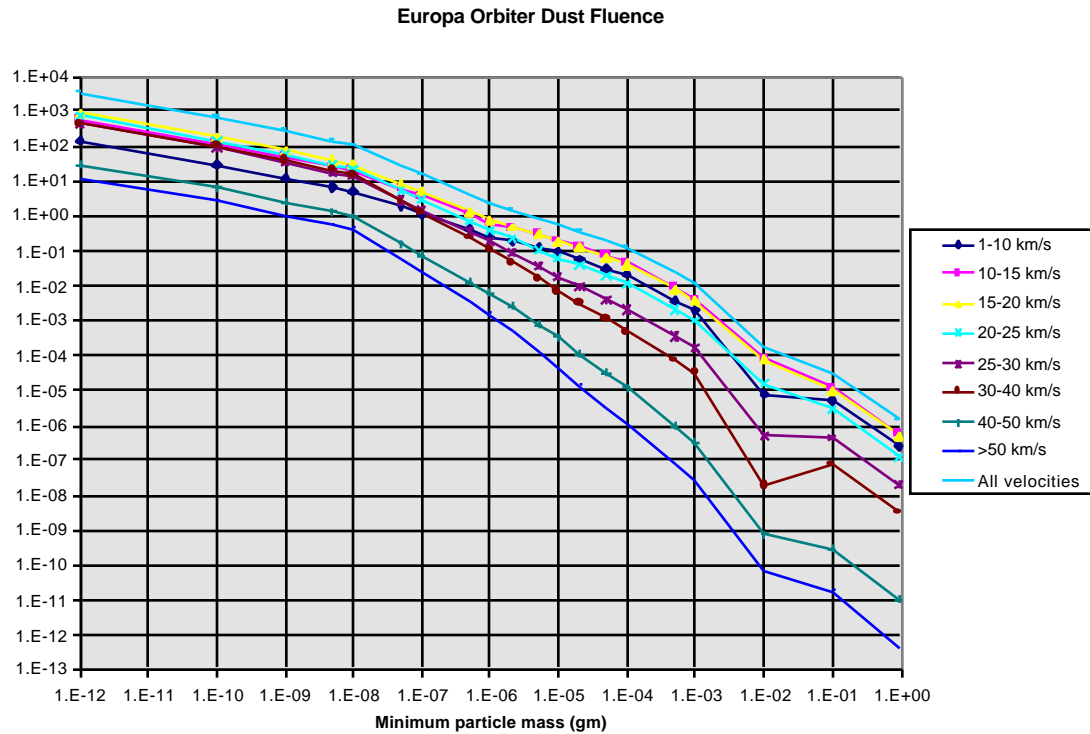
Figure 18.　Integral Europa Orbiter dust particle fluence

Table 5 gives the expected fluence of particles with masses and velocities great enough to penetrate 100 mils of aluminum assuming a particle density of 2.5 gm/cm^3. Fluences are shown for surfaces having random orientation in space, orientated normal to the spacecraft velocity vector (+v), and oriented normal to the spacecraft negative velocity vector (-v). Over 85% of the total fluence is accumulated in the first year after launch primarily on surfaces facing the spacecraft velocity direction, which is roughly the +Z direction during cruise to Jupiter. Proposers will need to consider whether or not they need to provide protection for their instruments against such micro-meteoroid impacts.

Table 5.   Fluence (number/m^2) of 2.5-gm/cm^3 particles on the Europa Orbiter spacecraft that will penetrate 100 mils of aluminum

	Surface Orientation		
Time Period	Random	+v	-v
Entire mission	0.094	0.17	0.0053

Other environmental requirements are defined in the "Environmental Requirements" document of the Outer Planets Program Library, available over the Internet through URL http://outerplanets.LaRC.NASA.gov/outerplanets

2.3   Mission Development Concept

2.3.1   Flight System Design and Deliveries

Though the three OP/SP spacecraft will be launched over a period of 3-4 years, the initial spacecraft design will be performed by the same personnel assigned to a joint design team. This team will continue into the detailed design of the Europa Orbiter and Pluto-Kuiper Express spacecraft while identifying areas of commonality for incorporation later into the detailed design of the Solar Probe spacecraft. Common subsystem designs will be used wherever possible to minimize the cost of developing and testing each spacecraft.

The OP/SP Project expects to employ the JPL Mission Data System (MDS) as its end-to-end data system. The MDS is currently under development and comprises both flight and ground software used by multimission and project personnel to operate the spacecraft. MDS will be used in software development, system test, and in actual mission operations and will enable the missions to collect, transport, store and act on both commands and telemetry. The MDS software architecture employs an object-oriented approach. The MDS spacecraft component will provide a standard interface to the science instruments including time synchronization, commands, data acquisition, memory loading, and memory readout functions. The software architecture is designed such that a core set of software functions are coded and used for all missions. Some mission-specific software will be required to specifically address those unique aspects of each mission, spacecraft, and payload. This core architecture will allow for software reuse, reduced cost in the development and testing of the software, smaller flight operations, faster sequence turn-around times, and improved science return in the event of required failure recovery responses.

Science proposers who intend to exploit available spacecraft computer resources will need to be compatible with the MDS software architecture and design, at least for software that is

resident in the Spacecraft Flight Computer (SFC). The extent to which any instrument flight software that runs on an internal instrument computer or any investigator-generated ground sequence planning, Ground Support Equipment, or data analysis software will need to adhere to MDS standards will be specified in an OP/SP Software Management Plan. Instrument proposers should plan to have at least one software expert in residence at JPL for at least 6 months prior to instrument PDR for training in the MDS methodology, development environment, and tools. MDS coding will be in C^{++}, and the operating system is VxWorks/Tornado. The required software licenses will be provided by the Project. MDS documentation will be provided including a Development Plan specifying the software development process, coding standards, review criteria, and configuration management approach; a Capabilities Catalog describing the capabilities supported by the MDS architecture; and a Users Reference Guide. Science instrument providers will be expected to participate in developing command and telemetry dictionaries, associated system design constraints, and instrument flight rules and constraints.

The planned X2000 First Delivery includes multimission avionics, software, and other equipment for the three missions. The recurring cost for the flight equipment is expected to be comparatively low. The propulsion modules and science packages are unique, however, and they will be a significant factor in the total cost of those missions. These mission-unique costs are borne by each individual mission, but by using common flight support and test equipment and common ground and flight software modules, each mission can reduce its integration and test costs.

Whenever possible, leveraging of technology developments supported by other NASA missions and/or technology development programs will be used where the capabilities match the needs of OP/SP. Such arrangements include incorporation of technologies supported by the New Millennium and Mars Programs. Some mission-unique technology (e.g., heat shield/antenna for Solar Probe) requires that OP/SP wholly support the development.

Standard, reasonable services will be provided the instruments during integration and testing at the system integrator's facility and the launch site. These include:

- Sterile dry N_2 purge (to be connected after receipt at the system integrator). It is the Instrument's responsibility to provide this during shipment and delivery into the integrator's facility.
- Office space with telephones and modem connections
- Laboratory space with limited tool capability in the integration facility.

A Spacecraft Test Laboratory will be developed at the system integrator's facility to simulate the spacecraft and software. The instruments shall provide software simulators of sufficient fidelity as well as breadboards and instrument simulators to support this effort.

2.4   Mission Operations Concept

2.4.1   Integrated Mission Flight Operations Team

The Europa Orbiter, Pluto-Kuiper Express, and Solar Probe missions will share a single core flight team and a common mission data system. This approach is enabled by the common X2000 avionics design shared by all three spacecraft together with a large percentage of common flight software. Each mission will supplement the shared operations capability with a few mission-dedicated personnel including mission planners, instrument representatives, and science investigation teams.

The core flight operations team will be supported by a university-based operations team, which will be competitively chosen in 2001. The university team will be delegated selected routine flight operations tasks to enhance the ability to operate multiple spacecraft simultaneously, to support educational outreach, and to provide a potential source of trained new-hires during the 15 years of flight operations. A workstation-based ground data system design makes implementation of a replica Project Operations Center (POC) at a university cost effective. Science workstations that allow science team members to interact with the operations system from remote sites will be developed as part of the ground data system design.

2.4.2   Beacon Mode Cruise

Routine Deep Space Network (DSN) tracking during cruise will be limited to a single, 4-hour pass every two weeks. This limit on telemetry and radiometric data collection and spacecraft commanding during cruise is intended to keep operations team costs low and reflects the new NASA full-cost-accounting policy, whereby missions are charged for DSN tracking time. To prevent a spacecraft anomaly from going undetected by the ground for a period of up to two weeks, a daily spacecraft beacon monitor track will be performed to establish that the spacecraft is on Earth-point and that no onboard event has been detected that requires ground interaction until the next regularly scheduled telemetry pass. The beacon signal generated by the spacecraft is a subcarrier tone that can be received by a small (5- or 10-meter) ground antenna and detected by a low-cost receiver / detector. The daily beacon monitor check for each spacecraft may be a task delegated to the university operations team.

On-board software that supports Beacon Mode operations includes fault detection and containment software that allows the spacecraft to safe itself during cruise for up to 2 weeks without ground action. Advanced engineering data summarization, onboard alarm limit checking, onboard performance trending, and adaptive anomaly data capture capabilities will also be provided.

The assumption is that science instruments are powered off during cruise except as required for instrument survival. Approximately once a year, or as negotiated with the Principal Investigators, the instruments will be turned on, calibrated, and tested, along with encounter sequence macros that have been developed during the year. Extra DSN tracking during this week will be provided to support the additional commanding and telemetry data collection required. This annual instrument turn-on week will probably be scheduled to occur during planned science team meetings.

OP/SP data management and data transport protocols will be X2000 MDS-based and will exploit multimission TMOD data services that will have been upgraded to support the MDS design. The MDS design assumes a common flight/ground file-based data management framework. Files will be used to package and store logical data units (objects) that may not map well into the packet model. The goal is to have management of both onboard data files and ground data files appear similar to the user. File management will support long-popular storage/access capabilities for numerous types of nontelemetry data products. File-based transport protocols will be provided for both spacecraft-to-ground and ground-to-ground nodes. Packetization will be provided as the underlying mechanism of flight-to-ground file data transport. The goal is to make packetization invisible to file-based data management and transport. An implication of this approach is that needed time tags and other ancillary data provided in packet headers and ancillary data packets in the traditional packet-based, data-stream-based systems will have to be provided within the data objects/data files.

2.4.3   Encounter Operations

Transition from cruise operations to encounter operations for the Europa mission starts at JOI - 60 days. Starting at this time, DSN coverage will increase, along with operations team staffing to support higher activity levels and mission critical events. If available within mission constraints, operations resources will be available to support instrument calibration and serendipitous science observations during Jupiter orbits and satellite flybys for the Europa mission. The Europa mission satellite "tour" will be designed to optimize trajectory efficiency to get into Europa orbit rather than to optimize satellite flyby science opportunities.

2.5   Project Schedule

The preliminary Europa Orbiter schedule is given in Figure 19.

Outer Planets-Solar Probe Top Level Schedule
Europa Orbiter (Preliminary)
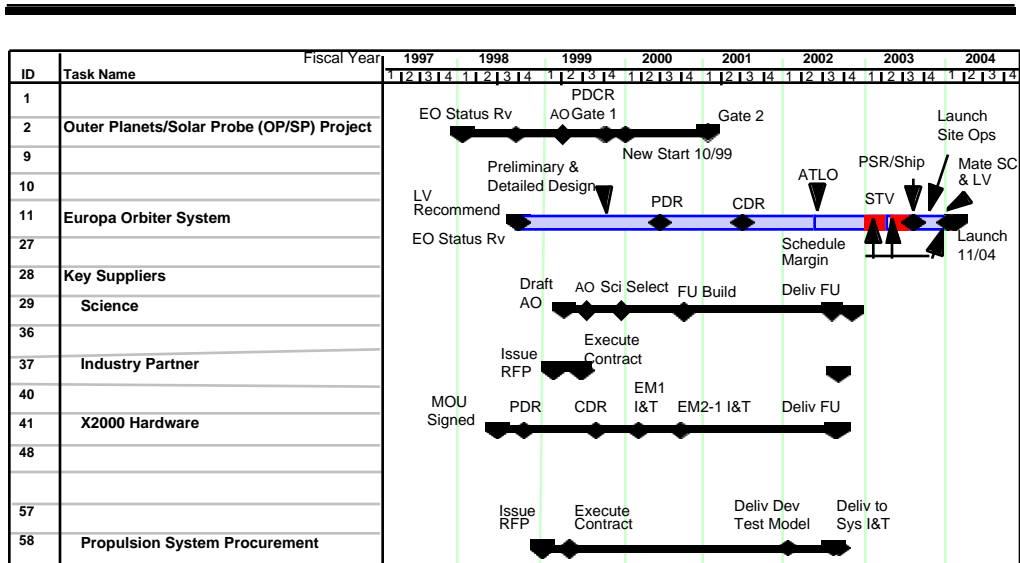
Figure 19.   Preliminary top level schedule for Europa Orbiter

3.   Science Investigations

3.1   Resources for the Science Investigations

As part of the strawman spacecraft design, an allocation of resources was made for the science payload. Since the only instrument hardware being solicited by this AO is an optical remote sensing package, the mass and power allocations of 10 kg and 7.5 watts and the volume, FOV, and thermal power dissipation allocations apply only to that package. Additional details on spacecraft capabilities supporting science are given in Sec. 2.2.2. The computer, bus bandwidth, data storage, and downlink data rate resources must be shared between all of the science investigations.

Table 6 summarizes the resource allocations for the Europa remote sensing science and radar payload. The resource allocations are listed in order of criticality. Proposals that fall outside the allocations for the resources of higher criticality will have a lower probability of selection. Proposals that exceed lower criticality resource allocations will not be penalized provided that they also undersubscribe some higher criticality resource.

Table 6.   Europa remote sensing science instrument resource allocations in order of criticality

| Resource | Criticality | Units | Allocations | |
			Remote Sensing	Radar
Mass	Higher	kg	10	N/A
Power (average)	Higher	watts	7.5	N/A
Cost	Higher	M$ (real yr)	19	N/A
Data storage	Lower	Gbits	1.2	1.0
Computer processing	Lower	MIPS	5	25
Downlink data rate	Lower	kbps	12	2
Bus bandwidth (asynchronous)	Lower	Mbps	10	20
Volume (internal)	Lower	cm	20x40x12	N/A
Volume (external)	Lower	cm	22x35x40	N/A

The power allocation includes power required for instrument heaters for thermal control. Decontamination heaters may exceed this power allocation, but, if so, their use will be limited by power availability. Any instrument purge equipment beyond fittings and internal plumbing that are part of the instrument will not have its mass charged against the above instrument allocations. Any instrument covers must be included in these allocations even if they are jettisoned. Radiation shielding mass must also be included within the mass allocation. The spacecraft data handling capabilities for science are allocated to radar and remote sensing in the above table assuming they are operating simultaneously. If only one of these instrument packages is operating during a given period, it could use the combined data handling allocations for both packages. Note that no real-time downlinking of radar or remote sensing data is planned; all downlinking is of stored data, and the allocations represent the average rate of downlinking each instrument's stored data over the course of a downlinking period. The downlink allocations are based on using the guaranteed 5-W transmitter power level. If adequate power is available, the 20-W transmitter power level could be used. However, proposals should base their science observing scenarios on the 5-W level. These scenarios should assume that of the 30 days in Europa orbit, 12 are dedicated to gravity tracking (no radar or remote sensing) and 18 are dedicated to radar and remote sensing observing and data return.

Investigations may exceed the allocated levels of data storage and computer processing MIPS by including the required extra memory or computer as part of their own hardware deliverable. X2000 parts are available for use by science investigators for this purpose as listed in the "Description Of X2000 Components Available For Use In Instrument Proposals" document of the Outer Planets Program Library, available over the Internet through URL http://outerplanets.LaRC.NASA.gov/outerplanets. The cost and mass to cover use of such parts must be included in the instrument totals.

It is anticipated that teams of approximately six radar science and six gravity science investigators will be selected via this AO and that the remote sensing science team will be kept small for reasons of efficiency and economy. The total funding available in real year dollars to support these investigator teams (over and above the instrument development costs allocated in Table 6) is as follows:

Team	Development phase	Operations phase
Remote sensing	$2.0M	$7.4M
Radar science	$1.0M	$3.9M
Gravity science	$1.0M	$3.5M

The suggested level of funding for facility instrument Team Leaders and individual Team Members is:

Radar Team Leaders	$0.375M	$1.4M
Radar Team Member (each)	$0.125M	$0.5M
Gravity Team Leader	$0.375M	$1.25M
Gravity Team Member (each)	$0.125M	$0.45M

Table 7 gives the anticipated profile of available funds by fiscal year for each investigation (hardware plus science investigators). Proposals should not plan to exceed these yearly funding levels by more than 20% in any given year unless funding below the indicated level is carried forward from an earlier fiscal year. In no case shall the total funding for the investigation exceed the allocated total.

3.2   Interaction with the Project

3.2.1   Project Fiscal Policy

Items pertinent for consideration by proposers in preparation of responses to this AO can be found in the following sections.

Table 7. Investigation (instrument and investigators) New Obligation Authority funding profile guideline in millions of real year dollars for the development and operations phases

Development Phase							
FY	99	00	01	02	03	04	Sum
Remote Sensing	0.3	4.5	7.5	7.6	1.0	0.1	21.0
Radar Science	0.1	0.2	0.2	0.2	0.2	0.1	1.0
Gravity Science	0.1	0.2	0.2	0.2	0.2	0.1	1.0
Operations Phase							
FY	04	05	06	07	08	09	Sum
Remote Sensing Team	0.2	0.3	0.7	2.0	2.4	1.9	7.4
Radar Science Team	0.1	0.1	0.4	1.0	1.3	1.0	3.9
Gravity Science Team	0.1	0.1	0.3	1.0	1.1	0.9	3.5

3.2.1.1 Budgetary Authority

NASA will annually allocate New Obligation Authority (NOA) to JPL for the Outer Planets/Solar Probe Project based on an Implementation Plan and updates submitted by the Project. In turn, the Project Office will allocate NOA annually to the Project Work Breakdown Structure primary elements based on the NASA NOA, the plans submitted by the leaders of each element (two of whom are the Chief Scientist and the Flight Instrument Development Manager), and the needs of the Project. Each mission (Europa, Pluto, and Solar Probe) has a Project Scientist, and one of them has additional duty as Chief Scientist. The Science Investigation Principal Investigators whom NASA selects through this AO will negotiate their Statements of Work (SOW's), budget submissions, and authority with the Flight Instruments Development Manager, who will be assisted in these negotiations by the appropriate Project Scientist. The resulting (SOW) and funding schedule will be documented in a contract between JPL and the PI's institution; this contract will be modified, if necessary, through the course of mission development and operations, covering the period of time from contract award to final delivery of science products after the end of the mission.

3.2.1.2 Cost-Capped Mission Budget Environment

Proposers must understand that NASA and JPL budgets for all OP/SP activities are strictly cost-capped. This capped cost includes launch vehicles, integration and interfaces, launch operations, and all flight and ground systems. Mission operations phase costs, including science operations and data analysis, will be similarly capped for each mission. Total

project costs will be a primary consideration in all design and development decisions and activities. Other requirements will have flexibility and will be prioritized to provide adequate margins and options for staying within cost and schedule constraints.

3.2.2 Project Organization

Overall project leadership and coordination is provided by the Project Manager and Project Office staff. The project is organized as shown in Figure 20. The Chief Scientist is a member of the Project Office staff, is appointed by the Project Manager and reports to the Project Manager.
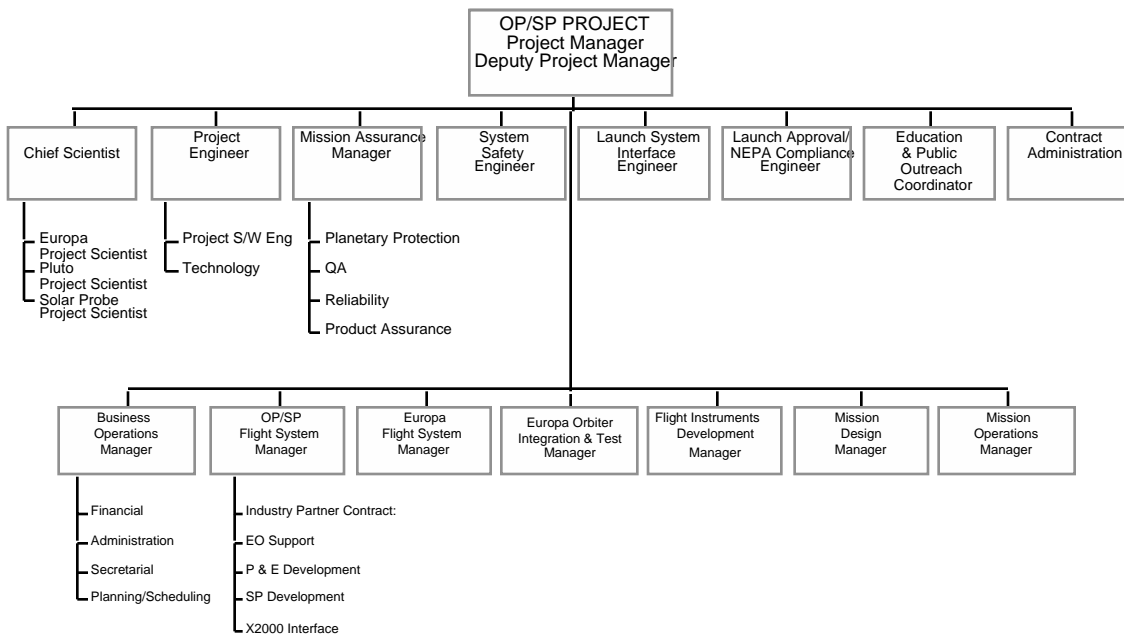

Figure 20. Organization chart for the Outer Planets/Solar Probe Project.

3.2.2.1 Science Investigators as Members of Project Teams

PI's and their lead instrument developers will become members of an integrated implementation team for their respective mission.

Primary interfaces with each mission implementation team will be in the following areas:

1. Trajectory/Navigation/Mission design.
2. Flight System (including mechanical and electronic interfaces, major system trades).
3. Software Development.
4. Mission Assurance (including electronic parts, risk management, quality assurance).
5. Assembly, Test and Launch Operations.
6. Mission Operations and End-to-End Data Flow (including flight/ground Mission Data System).

The avionics, software, and mission data system for the three missions (and other "customer" missions) will be developed in common by the X2000 First Delivery Project, based at JPL, and their numerous partners and contractors in industry, academia, and Government. Some of the electronic parts developed by X2000 will be available for use in science instruments, such as microcontrollers, memory, and power converters (see the "Description Of X2000 Components Available For Use In Instrument Proposals" document of the Outer Planets Program Library, available over the Internet through URL http://outerplanets.LaRC.NASA.gov/outerplanets). Each item is intended to be made available commercially and can be considered in the design of the instrument. The OP/SP Project will handle all interfaces with X2000 and will consult with PI teams as appropriate.

3.2.2.2 Relationship Between Science Teams and the Outer Planets/Solar Probe Project

The Project Scientist for Europa will have overall responsibility for the coordination of the mission's science and the achievement of the mission science objectives through chairmanship of the Mission Science Team, the other members of which will be the Science Investigation Principal Investigators and Team Leaders.

Principal Investigators and/or key members of their teams will need to be available for frequent on-line concurrent working sessions. In addition, co-location of key Science Investigation Team members may be required during high-activity periods.

As with the mission design, details of the project organization and interactions will evolve over time to meet the needs of the project and mission.

3.2.3 Encounter Science Team Selection, Participation, and Management

The OP/SP development and operations environment will require that individuals selected to produce the science investigations work closely with JPL and other team members on

producing investigation hardware, software, mission design, and the flight system which supports the investigations. It is anticipated that the instrument teams selected in response to this AO will be small and consist mainly of those who will design hardware and software for the mission. Scientists whose role would be primarily in the areas of data reduction and analysis and interpretation of the resulting information will not be funded as part of the initial team in order to save costs.

After launch and as the spacecraft near their science targets, NASA plans to select via a to-be-determined process a broader team of scientists to provide the expertise required to successfully conduct the observations and reduce, analyze and interpret the data. The core of the team, it is anticipated, will be those who designed the investigations during the prelaunch phase, with possible changes reflecting career moves, retirements, and the evolving knowledge base in planetary and solar science. The intent is to retain the crucial expertise needed to fulfill the science investigation, while bringing in new people who can maximize the value of the science returned from the mission.

3.2.4   Mission Assurance Requirements

OP/SP mission assurance requirements for science instruments can be found in the "Instrument Mission Assurance And Safety Requirements" document of the Outer Planets Program Library, available over the Internet through URL http://outerplanets.LaRC.NASA.gov/outerplanets.

3.2.5   Principal Investigator and Team Leader Responsibilities

Science instrument Principal Investigators (PI's) are responsible for instrument design and development, fabrication, test, calibration, and delivery of flight hardware, software, and associated support equipment, within project schedule and payload resources. The PI's are responsible for planning and operational support of instrument operation, data analysis and overall conduct of each of their investigations.

A PI-funded instrument engineer for each instrument will represent the payload at the spacecraft integrator's site as a participant in the integrated development teams and to negotiate interfaces.

The specific responsibilities of the instrument PI include, but are not limited to, the following:

1. Developing an internal management plan and an experiment implementation plan.
2. Ensuring that the design, fabrication, development, and testing of the investigation flight elements are appropriate to the objectives of the investigation and assure qualification to the environmental and interface constraints.
3. Managing hardware and software margin to ensure successful integration and implementation of the experiment.
4. Hardware and software quality assurance and reliability and selection of parts and materials.
5. Ensuring that instrument hardware and software development meets the approved schedules and cost plans.
6. Establishing requirements, Interface Control Documents (ICD's), schedules, and transfer of funds through negotiation with the Project.
7. Ensuring the flight hardware is flight qualified and properly calibrated.
8. Participating in Project Science Group (PSG) meetings and associated working groups. PSG meetings will be held in conjunction with PI Working Group meetings every 6 months.
9. Conducting payload reviews.
10. Participating in Software Working Group (SWG) meetings, as required by the proposed science use of spacecraft computational resources and services to resolve requirements, process issues, and interface issues and to resolve resource allocations and operational timelines.
11. Supporting payload integration and system test procedure development and maintenance and payload hardware and software integration.
12. Participating in flight system tests and integrated end-to-end ground system tests and operation of any payload-unique Ground Support Equipment (GSE) in these tests.
13. Supporting definition of mission database contents, including, but not limited to, flight rules and constraints, sequences, payload telemetry, and commands.
14. Supporting integrated mission data/sequence development and flight software integration.
15. Supporting launch site operations planning, including safety, and launch site system tests at Kennedy Space Center/Cape Canaveral Air Force Station.
16. Planning and executing mission operations.
17. Ensuring that the reduction, analysis, reporting, and archiving of the results of the investigation meet with the highest scientific standards consistent with budgetary and other recognized constraints.
18. Preparing, certifying and releasing a final data product (to PDS) within six months or less of data receipt on the ground.

The specific responsibilities of the Science Team Leader include, but are not limited to, the following:

1. Developing an internal management plan and an experiment implementation plan.
2. Establishing requirements, schedules, and transfer of funds through negotiation with the Project.
3. Participating in Project Science Group (PSG) meetings and associated working groups. PSG meetings will be held in conjunction with PI Working Group meetings every 6 months.
4. Supporting definition of mission database contents, including, but not limited to, flight rules and constraints, sequences, payload telemetry, and commands.
5. Supporting integrated mission data/sequence development and flight software integration.
6. Supporting launch site operations planning, including safety, and launch site system tests at Kennedy Space Center/Cape Canaveral Air Force Station.
7. Planning and executing mission operations.
8. Ensuring that the reduction, analysis, reporting, and archiving of the results of the investigation meet with the highest scientific standards consistent with budgetary and other recognized constraints.
9. Preparing, certifying, and releasing a final data product (to PDS) within six months or less of data receipt on the ground.

The specific responsibilities of individual Science Team members include, but are not limited to, supporting and assisting the Team Leader in carrying out his/her responsibilities.

3.3   Deliverables

3.3.1   General

The deliveries by the instrument Principal Investigator to the Project include, but are not limited to, the following:

1. Sign a Memorandum of Agreement with the Project that documents resource allocations.
2. Provide and maintain required documentation, including ICD's (see Section 3.E)
3. Support development and maintenance of ICD's.
4. Provide monthly Technical Progress Reports and monthly Financial Management Reports.
5. Deliver flight-qualified hardware to the flight system integrator with suitable shipping containers and any protective covers required.

6. Deliver either an Engineering Model, Protoflight unit, or a payload mass simulator and payload data interface simulator to the flight system integrator.
7. Provide necessary payload-unique GSE for stand-alone integration and launch operations.
8. Provide payload unit history log books including power-on time log.
9. Deliver investigation flight software to be resident in the spacecraft flight computer (see Section 3.3.3).
10. Provide timely information to establish and maintain controlled baselines for software interfaces, shared computational resources, mission data, and mission operations timelines and sequences.
11. Archival science data products.

The deliverables by the science Team Leader to the Project include, but are not limited to, the following:

1. Sign a Memorandum of Agreement with the Project that documents resource allocations.
2. GDS/MOS requirements document inputs.
3. Archival science data products.

Individual science team members will support and assist the Team Leader in producing his/her required deliverables.

3.3.2 Hardware Delivery

The payload data interface/mass simulator, Engineering Model, or Protoflight unit must be delivered to the flight system integrator's site on or before 18 months before launch. The science payload flight units must be delivered on or before 15 months before launch. Payload flight units must be accompanied by all ground support equipment needed to support system test. Unit history log books shall accompany the flight hardware. Payload flight units must be fully qualified and calibrated before delivery; instruments will not be returned again to the PI.

3.3.3 Software

The OP/SP Software Management Plan will specify requirements on software documentation, testing, source materials, reviews, and metrics.

3.3.3.1 Software Documentation - Software/Computer Systems Interface Control Document (ICD)

Initial definition of operational timeline requirements and related resource demands (characterized by peak and typical parameters) will be negotiated in compliance with resource usage constraints placed on the science payload by the Project and documented in a software-specific section of the Preliminary ICD (with Initial Software Requirements) for:

1. Volatile and nonvolatile memory
2. Process activation frequency and duty cycle
3. Storage demands with storage duration's
4. I/O requirements for all classes (data bus bandwidth, command/telemetry bandwidth) including best available information on compliance with protocol standards or any unique data transfer methods.

Updated information for all items in the Preliminary ICD, with projections of final commitments for all resource demands, plus protocol compliance for all transactions using the spacecraft C&DH, including behavioral characteristics of timing where it is relevant to correct operations of the science payload/mission, is due with the Update Software Requirements ICD.

The committed baseline for all elements of the Software/Computer System Section of the ICD is the third delivery, due with the Final Software Requirements ICD.

3.3.3.2 Software Documentation - Other

Requirements, design, build, test, and evaluation information that provides insight into the software implementation should be provided as they become available, in accordance with the PI's normal development plan.

3.3.3.3 Software Test: Required Evaluation Procedures

Software test procedures are required and are subject to approval. The fidelity of the procedure and level of approval corresponds to the potential risks involved in the procedure. Generally, as the software testing is done in primarily a simulation and Engineering Development Unit (EDU) environment, the risk is minimal, requiring approval from only the cognizant personnel for the item under evaluation and Spacecraft Test Laboratory (STL) operations. Circumstances that may require further approvals include:

1. Use of flight hardware in the configuration
2. Requirements for special interfaces - either hardware or software - that may require test setup and verification

3. Exclusive operations or continuous operations that produce resource conflicts not reconcilable among other parties.

3.3.3.4   Software Source Materials

The mission load (all executable spacecraft and payload flight software and data) is generated as an integrated load image, including initial/nominal values for all updatable mission data/system files. To develop the mission load, source code for compilation, materials for binding, and data/file load shall be provided in a timely fashion to support software development integration in the Spacecraft Test Laboratory, assembly and integration tests during science payload integration, and mission readiness tests at the launch site. The Final Software Baseline Delivery for launch is scheduled at the time of flight hardware delivery, prior to the start of science integration for final build and characterization of the launch configuration load image. Other postlaunch flight software updates are expected.

3.4   Payload Reviews

The payload PI(s) and science Team Leaders will be expected to attend the spacecraft Preliminary Design Review (PDR) and Critical Design Review (CDR), ground system reviews, and any informal reviews scheduled by integrated development teams with payload participation requiring the PI rather than the instrument engineer.

Each instrument PI will host a Preliminary Interface Requirements and Design Review (PIRDR) for their investigation. The PIRDR is scheduled as early as possible after the completion of the Functional Requirements Document (FRD)/Experiment Implementation Plan (EIP). Topics include: discussion of the EIP, discussion of the FRD, description of interfaces, I/F verification plan, and description of the safety plan.

Likewise, each PI will host a Final Interface Requirements and Design Review (FIRDR). The FIRDR occurs prior to the mission CDR, at the completion of the payload detailed design. Topics include: status of hardware design, fabrication, test, and calibration, software design and test plans, plans for integration, description of support equipment, finalization of interfaces, command and telemetry requirements, and discussion of environmental and system tests.

Prior to delivery of the flight instrument, each instrument PI will hold a Hardware Requirements Certification Review (HRCR) to ensure that the instrument meets all of its requirements and is ready to be shipped for integration on the spacecraft.

3.5   Documentation Requirements

The following is a list and description of the minimum formal documentation that will be required from instrument PI's:

1.   Memorandum of Agreement
2.   FRD/EIP/Safety (Combined)
3.   GDS/MOS Requirements (Preliminary and Final)
4.   ICD Major Milestones:
        Preliminary (with Initial Software Requirements)
        Final (Start Configuration Control)
        Update Software Requirements
        Final Software Requirements
5.   Instrument Design Description
7.   Payload Handling Requirements List
8.   Unit History Log Books
9.   Acceptance Data Package

Science Team Leaders must provide:

1.   Memorandum of Agreement
2.   GDS/MOS Requirements (Preliminary and Final)

Individual science team members will support and assist the Team Leader in generating these documents.

3.5.1   Memorandum of Agreement

A Memorandum of Agreement documents the investigation resource allocation (mass, power, volume and fiscal resources) between the project and each investigation PI and Team Leader. This is written immediately after payload selection and signed by the Project Manager, PI or Team Leader, and spacecraft flight system integrator designee for hardware investigations.

3.5.2   Functional Requirements Document (FRD) / Experiment Implementation Plan (EIP) / Safety Plan

Each instrument PI is responsible for writing a combined Functional Requirements Document and Experiment Implementation Plan for their investigation within 3 months of selection.

Contents are negotiated with the project manager, but may be assumed to include:

1. Payload functional requirements,
2. Hardware development-and-test plans and schedule, including reliability and quality assurance plans,
3. Software development-and-test plans and schedule,
4. Cost plan for hardware and software development, fabrication, test, and calibration from selection through launch,
5. Margin management plan
6. Post-launch cost plan for instrument operation, data analysis, and data archiving,
7. Requirements for project support,
8. Personnel and hardware safety plans,
9. Contamination control plan
10. Calibration plans,
11. Science management and investigation plan,
12. Payload portion of range safety plan and payload safety at launch site.
13. Fracture control plan (for Space Shuttle launched payloads).

3.5.3   Ground Data System (GDS) / Mission Operations System (MOS) Requirements

Ground Data System / Mission Operations System requirements due dates are listed below. These primarily address instrument operation requirements and flight rules.

	Europa	Pluto	Solar Probe
Preliminary	9/00	9/01	9/04
Final	9/02	9/03	9/06

3.5.4   Interface Control Documents (ICD's)

ICD's are negotiated directly with the spacecraft engineering team in an integrated-development-team environment, with Preliminary ICD's required by the spacecraft PDR and final ICD's under configuration control by the spacecraft CDR. ICD's identify all payload interfaces, including, but not limited to, the volume envelope, mounting, center of mass, electrical and mechanical connections, end circuits, pyro devices, features requiring access or clearance, purge requirements, software requirements, testing, facility support, view angles, clearances, etc.

3.5.5   Instrument Design Description Document (IDDD)

The final design of the payload is documented in an IDDD. The IDDD is due at the HRCR. Included in the IDDD are the parts and materials list.

3.5.6   Payload Handling Requirements

A payload handling requirements list must be supplied prior to the delivery of flight units to the spacecraft integrator. This checklist describes any special handling necessary to ensure the safety of the flight hardware.

3.5.7   Unit History Log Book

The Unit History Log Book accompanies the delivery of the flight hardware.

3.5.8   Acceptance Data Package

The Acceptance Data Package includes (but is not limited to) final drawings, documents, mass properties, qualification data, footprint drawings, final power, etc.

4.   References

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4.   Moore, J.C., A.P. Reid, and J. Kipfstuhl, Microphysical And Electrical Properties Of Marine Ice And Its Relationship To Meteoric And Sea Ice. *J. Geophys. Res 99,* 5171-5180, 1994.

5.   Tsang, L., Kong, J.A., Shin, R.T., *Theory of Microwave Remote Sensing*, Wiley-Interscience, New York, 1985.